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COMPUTER PROGRAM FOR PREDICTION
OF AXIAL FLOW TURBINE PERFORMANCE

by

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ABSTRACT:

The report presents a computer program for prediction of performance of single-stage axial turbines of given geometry. The three-dimensional method developed by Vavra is applied, taking account of streamline curvatures and slopes, as well as enthalpy and entropy gradients in the solutions of the equation of motion, and of boundary layer thicknesses in the continuity equation.

A choice among five different loss correlation methods and two flow angles correlations is offered. Loss coefficients and flow angles are automatically calculated from blading geometry and actual flow conditions for every streamline, according to the selected correlation method.

A fair agreement of predictions with several actual turbines experimental results was found in ref. [4], where also the applicability of different available correlations is discussed.

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SYMBOLS

A	Area (in^2)
A_{CL}	Tip clearance area (in^2)
a	Throat opening of blade channel (in)
$\bar{a}$	Non-dimensional throat opening, a/a_m
C	Blade chord, see Fig. 6 (in)
$c\ell$	Rotor tip clearance (in)
c_p	Specific heat at constant pressure (BTU/lb_m-^oR)
dA_n	Infinitesimal area, perpendicular to the flow (in^2)
E	Blade radius of curvature, see Fig. 6 (in)
$\vec{f}_f$	Frictional force per unit mass (lb/slug)
H	Total enthalpy (BTU/lb_m)
H	Boundary layer form factor
K	Boundary layer energy factor
K_{CL}	Coefficient, see eq. (31)
k	Curvature coefficient, see eq. (16)
$\vec{i}$	Unit vector
i	Incidence angle
L	Mean distance between the stations 0 and 1 and 1 and 2 (in)
M	Mach number
m	Boundary layer exponent
$\dot{m}$	Mass flow rate (slug/sec)
$\dot{m}_{CL}$	Mass flow rate passing thru the rotor tip clearance (slug/sec)
NSETS	Number of conditions for which performance values have to be found
O	Blade opening (in)
P_T	Total pressure (psi)
p	Static pressure (psi)
q	Heat exchanged with external sources per unit mass (BTU/lb)
R_G	Gas constant (ft-lb/lb_m-^oR)
R_H	Radius at blade hub (in)
R_T	Radius at blade tip (in)
r	Radius (in)
S	Entropy (BTU/lb-^oR)
S^*	Non-dimensional entropy, S/c_p

T	Blade maximum thickness, see Fig. 6 (in)
T	Static temperature (^{o}R)
T_T	Total temperature (^{o}R)
TE	Thickness of blade trailing edge, in peripheral direction, see Fig. 6 (in)
TN	Thickness of blade trailing edge, in normal direction, see Fig. 6 (in)
t	Time (sec.)
u	Peripheral velocity (ft/sec)
V	Absolute velocity (ft/sec)
W	Relative velocity (ft/sec)
x	Non-dimensional radius, r/r_m
X_e	See eq. (30)
Y	Non-dimensional axial velocity, V_A/V_{Am}
Y	Total pressure loss coefficient, see eq. (40)
z	Number of blades

GREEK SYMBOLS

α	Absolute gas flow angle, see Fig. 5 (deg or radians)
β	Relative gas flow angle, see Fig. 5 (deg or radians)
β^*	Pressure ratio, see eq. (44)
β_o	Blade inlet angle, see Fig. 5 (deg or radians)
γ	Specific heat ratio
$\Delta\eta_{CL}$	Decrease in efficiency, due to rotor tip leakage, see eq. (47)
ΔR	Streamline displacement, see Fig. 1
δ_r	Streamline displacement, see Fig. 1
ζ	Kinetic energy loss coefficient
ζ^*	Kinetic energy loss coefficient used in the continuity equation, see eq. (28)
ζ_o	Kinetic energy loss coefficient for low Mach numbers, see eq. (42)
ζ_{CL}	Kinetic energy loss coefficient due to rotor tip leakage, see eq. (47)
η_{TS}	Total/static efficiency
η_{TT}	Total/total efficiency
θ	Angle between two radial planes (deg. or radians)
λ	Angle between the flow and the axis of the turbine in a meridional plane (deg. or radians)
μ	Gas viscosity (lb/sec-ft)
ξ	Area restriction factor, see eq. (27)
ρ	Gas density (lb_m/ft^3)
Φ	Non-dimensional flow function
X_ρ	Coefficient in Traupel's method of loss correlation, see eq. (46)
$\vec{\omega}$	Angular velocity (radians/sec)

SUBSCRIPTS

A	Axial
E	Equivalent
is	Isentropic expansion from total inlet conditions
m	Mean streamline
m	Meridional
R	Rotor
r	Radial direction, cylindrical coordinates
S	Stator
z	Axial direction, cylindrical coordinates
θ	Peripheral direction, cylindrical coordinates
o	Station ahead the stator
1	Station between stator and rotor
2	Station after the rotor

INTRODUCTION

An accurate knowledge of performance achievable with turbines of fixed geometry, both at design and off-design conditions, is important in advanced propulsion and power systems. The more accurate the prevision is, the more meaningful the optimization of the turbine itself and of the overall system will be.

A first way to solve this problem consists in the testing of a prototype, but it presents several disadvantages, namely it is expensive and time consuming. Furthermore, if effects of turbine geometry changes have to be investigated, different prototypes will be required.

An alternative solution to the problem consists in theoretical methods of prediction. The present availability of high speed computers allows one to solve systems of differential equations and to perform a large number of iterations in a short time. Moreover computer programs give the possibility of changing imput data, so that a large variety of different turbine configurations and of working conditions can be investigated.

This report presents a computer program, derived by the three-dimensional calculation method given first by Vavra [1] and then developed by Eckert [2] and Harrison [3]. This method takes account of enthalpy and entropy gradients and of streamline curvatures and slopes in equations of motion, and of boundary layer thicknesses in continuity equation. It is applicable to single-stage axial turbines with unchocked flow.

A critical point in all theoretical performance calculations is the prediction of the losses that occur in the blade rows. In the present program, one can choose among five different loss correlation methods. For each method pertinent subroutines compute loss coefficients from blading geometry and flow characteristics. A comparative study of these methods can be found in [4], where they were applied to actual turbines of different design practices, in a wide range of all significant flow and geometrical properties.

The comparisons presented in [4] with experimental performance showed a fair agreement of predictions with all turbine stages that were examined.

The present report is divided into four sections: in the first the used equations are set up and necessary assumptions are discussed; in the second the method of solution is described; in the third different losses and discharge flow angles available prediction methods are described; and in the fourth the instructions for the use of computer program are given, with an example of imput and output data. Eventually in the appendix the FORTRAN list of the MAIN routine and of the 28 subroutines is given.

METHOD OF ANALYSIS

The flow in turbomachines is ruled by the three fundamental laws of fluid dynamics, namely:

Equation of Motion

Energy Equation

Equation of Continuity.

All proper three-dimensional calculation methods proposed in the technical literature solve the differential equations derived by these laws. Differences among these methods are due to the three following reasons:

- different stations are chosen where equations are solved;
- different hypotheses are formulated to describe the real processes occurring in the machine;
- different numerical methods are applied in the solutions of the equations.

As far as the first problem is concerned in the present method, the equation of motion is applied at three stations, namely ahead of the stator, after the stator, and after the rotor, indicated respectively with subscripts 0, 1, 2 in Fig. 1. On the contrary, since blade geometry is given, the continuity equation is applied at blade throat sections 1* and 2* in Fig. 1, as suggested in [5].

those occurring in the boundary layers along the blade surfaces, and flow frictional losses between blades can therefore be neglected.

Assumption 4) is reasonable for uncooled blades, where energy changes due to heat transfer are negligible with respect to those related to velocity changes. If blades are cooled, the additional term q in the energy equation must be specified. Assumption 5) is valid in most cases. If the thermodynamic processes occur in ranges where real gas effects are not too strong, average values of gas properties give good approximations.

Some additional assumptions, regarding streamlines slope and curvature, are discussed in the section pertaining to the equation of motion.

As far as the third problem is concerned, the numerical small difference method was found to give a good convergence, and was therefore applied for the solution of the differential equations.

The following sections give the derivations of the equations with the above-listed assumptions.

Equation of motion

The general equation of motion for relative flow in vectorial form, is:

$$\frac{\partial \vec{W}}{\partial t} + \nabla H_R = \vec{W} \times (\nabla \times \vec{W} + 2\vec{\omega}) + T \nabla S + \vec{f}_f \tag{1}$$

For absolute flow, where $\begin{cases} \vec{\omega} = 0 & (2) \\ \vec{v} = \vec{W} & (3) \\ H = H_R & (4) \end{cases}$, equation (1)

becomes:

$$\frac{\partial \vec{V}}{\partial r} + \nabla H = \vec{V} \times (\nabla \times \vec{V}) + T \nabla S + \vec{f}_f \tag{1a}$$

With hypothesis 1) $\frac{\partial \vec{W}}{\partial t} = 0$, $\frac{\partial \vec{V}}{\partial t} = 0$

and hypothesis 2) $\vec{f}_f = 0$

This allows one to more accurately evaluate the pressure drops occurring in blade channels, since in this way it is possible to account for boundary layer thicknesses. This problem is particularly important at high Mach numbers where a small change in flow area causes large differences in pressure ratios.

As far as the second problem is concerned, the following assumptions are made:

1) Steady flow

2) Frictionless flow at the stations where the equations of motion are solved.

3) Axisymmetric flow at the stations where the equations of motion are solved.

4) Adiabatic flow.

5) The working fluid is a perfect gas, namely a gas having the equation of state:

$$p = \rho R_G T$$

and specific heat at constant pressure is independent of temperature and pressure.

Hypotheses 1) and 3) are interrelated since the flow can be steady in both rotor and stator only if it is axisymmetric. Although they are correct only for cascades with an infinite number of blades, axisymmetry and steady conditions are necessary assumptions since any other hypothesis would require unknown quantitative information on flow inside the blade rows. One problem connected with these assumptions is that downstream conditions cannot affect the flow upstream. Therefore pressure distributions at rotor exit can deviate from those imposed by the discharge conditions.

With assumption 2), all entropy changes are supposed to occur in the blade rows ahead of the considered station. This assumption can be justified by the fact that velocity gradients in the regions, where the equation of motion is applied, are in all probability smaller than equations (1) and (1a) become respectively:

$$\nabla H_R = \vec{W} \times (\nabla \times \vec{W} + 2\vec{\omega}) + T \nabla S \tag{5}$$

$$\nabla H = \vec{V} \times (\nabla \times \vec{V}) + T \nabla S \tag{5a}$$

The following derivations for equation (5) are valid also for equation (5a), if substitutions (2), (3), (4) are performed.

It is convenient to express equation (5) in cylindrical coordinates (see Fig. 1 for symbols). Equating the three components of equation (5), the following equations are obtained:

a. tangential component:

$$\frac{1}{r}\frac{\partial H_R}{\partial \theta} = \frac{W_A}{r}\left[\frac{\partial W_A}{\partial \theta} - \frac{\partial (rW_u)}{\partial z}\right] - \frac{W_r}{r}\left[\frac{\partial (rW_u)}{r} - \frac{\partial W_r}{\partial \theta}\right] - 2\omega\, W_r + \frac{T}{r}\frac{\partial S}{\partial \theta} \tag{6}$$

b. meridional component:

$$\frac{\partial H_R}{\partial z} = W_r\left[\frac{\partial W_r}{\partial z} - \frac{\partial W_A}{\partial r}\right] - \frac{W_u}{r}\left[\frac{\partial W_A}{\partial \theta} - \frac{\partial (rW_u)}{\partial z}\right] + T\frac{\partial S}{\partial Z} \tag{7}$$

c. radial component:

$$\frac{\partial H_r}{\partial r} = \frac{W_u}{r}\left[\frac{\partial (rW_u)}{\partial r} - \frac{\partial W_r}{\partial \theta}\right] - W_A\left[\frac{\partial W_r}{\partial z} - \frac{\partial W_A}{\partial r}\right] + 2\omega\, W_u + T\frac{\partial S}{\partial r} \tag{8}$$

with hypothesis 3) $\frac{\partial}{\partial \theta}(\quad) = 0$

and hypothesis 4) $\vec{w}\, d\, t \cdot \nabla H_R = 0$

the system of equations (6), (7), (8) reduces to equation (9):

$$\frac{\partial H_R}{\partial r} = \frac{W_u}{r}\,\frac{\partial (rW_u)}{\partial r} - W_A\frac{\partial W_r}{\partial z} + W_A\frac{\partial W_A}{\partial r} + 2\omega\, W_u + T\frac{\partial s}{\partial r} \tag{9}$$

Using substitution: $H_E = H_R + \frac{u^2}{2}$ (10)

with hypotheses 5) $H = c_p\, T$ and 4) H_E = const (see Fig. 2)

$$T_2 = \frac{H_E}{c_p} - \frac{W_2^{\,2}}{2c_p} \qquad (11)$$

and introducing the non-dimensional quantities:

$$Y = \frac{W_A}{W_{Am}} \qquad (12)$$

$$X = \frac{r}{r_m} \qquad (13)$$

$$S^* = \frac{S}{c_p} \qquad (14)$$

Equation (9) becomes:

$$\frac{1}{Y^2}\frac{\partial Y^2}{\partial x} + \cos^2\beta\left(-\frac{2r_m}{W_A}\frac{\partial W_r}{\partial z} - \frac{1}{\cos^2\lambda}\frac{\partial S^*}{\partial x}\right) + 2\tan\beta\,\frac{\partial\beta}{\partial x}$$

$$+ \frac{2}{x}\sin^2\beta + \frac{4\sin\beta\cos\beta}{W_{Am}\,Y} + \frac{2\,U_m\,U\cos^2\beta}{W_A^{\,2}\,Y^2} - \frac{2\cos^2\beta}{W_{Am}^{\,2}\,Y^2}\,\frac{\partial H_E}{\partial x} +$$

$$+ \left[\frac{2\,H_E\cos^2\beta}{W_{Am}^{\,2}\,Y^2} - \sin^2\beta\right]\frac{\partial S^*}{\partial x} = 0 \qquad (15)$$

In this equation, terms containing $\cos\lambda$ and $\frac{\partial W_r}{\partial z}$ depend respectively on streamlines slope and curvature. Vavra [1] showed that the most reasonable assumptions, when only three points of a streamline are known, are the following (see Fig. 1 for symbols):

$$\frac{1}{W_A}\,\frac{\partial W_r}{\partial z} = \pm\, k\,\frac{\delta_r}{L^2} \qquad (16)$$

$$\cos^2\lambda = \frac{L^2}{L^2 + \left(\frac{\Delta R}{2}\right)^2} \qquad (17)$$

In equation (16) the positive sign holds for station (2) and the negative one for station (1), for δr positive as shown in Fig. 1. Suggested values for k are between 4 and 6. Finally with equations (16) and (17) into (15) the following equation is obtained:

$$\frac{d\,(\ln Y^2)}{dx} = -\cos^2\beta \left[2\,k\,r_m \frac{\delta r}{L^2} - \frac{L^2 + (\frac{\Delta R}{2})^2}{L^2} \frac{dS^*}{dx} \right]$$

$$- 2 \tan\beta \frac{d\beta}{dx} - \frac{2}{x} \sin^2\beta - \frac{4\,U_m \sin\beta \cos\beta}{W_{Am}\,Y} -$$

$$- \frac{2\,U_m\,U \cos^2\beta}{W_{Am}^2\,Y^2} + \frac{2\cos^2\beta}{W_{Am}^2\,Y^2} \frac{dH_E}{dx} - \left[\frac{-2\,H_E \cos^2\beta}{W_{Am}^2\,Y^2} - \sin^2\beta \quad \frac{dS^*}{dx} \right] \qquad (18)$$

For the station after the stator row, the following equation can be derived with (2), (3) and (4) in equation (18):

$$\frac{d(\ln Y^2)}{dx} = -\cos^2\alpha \left[(-2\,K\,r_m \frac{\delta r}{L^2}) - \frac{L^2 + (\Delta R/2)^2}{L^2} \frac{dS^*}{dx} \right] -$$

$$-2 \tan\alpha_1 \frac{d\alpha}{dx} - \frac{2}{x} \sin^2\alpha_1 + \frac{2\cos^2\alpha}{Y^2\,V_{Am}^2} \frac{dH}{dx} - \left[\frac{2\,H \cos^2\alpha}{Y^2\,V_{Am}^2} \right. -$$

$$\left. - \sin^2\alpha_1 \right] \frac{dS^*}{dx} \qquad (18a)$$

Equation(18a) could also have been derived directly from equation (5a).

In equations (18) and (18a) the last term is depending on flow irreversibilities due to frictional losses. The specific entropy S* will be calculated, after [1], by:

$$S^* = \ln\left[\frac{\dfrac{Y^2\,W_{Am}^2}{2\,H_E \cos^2\beta}}{1 - \dfrac{Y\,W_{Am}^2}{2\,H_E \cos^2\beta\,(1-\zeta)}} \right] + S_E^* \qquad (19)$$

and by:

$$S^* = \ln \left[\frac{\dfrac{Y^2 V_{Am}^2}{2 H_o \cos^2\beta}}{\dfrac{Y V_{Am}^2}{2 H_o \cos^2\beta(1-\zeta)}} \right] + S_o^* \tag{19a}$$

where ζ represents the kinetic energy loss coefficient which is established by the chosen loss correlation method.

Energy equation

The energy equation in a relative flow is given by:

$$\vec{W}dt\cdot\nabla (H_R) = \vec{W}dt\cdot\nabla(q) - \frac{\partial}{\partial t} (\frac{W^2}{2}) dt \tag{20}$$

and in an absolute flow, with (2), (3) and (4) in (20), :

$$\vec{V}dt\cdot\nabla (H_R) = \vec{V}dt\cdot\nabla(q) - \frac{\partial}{\partial t} (\frac{V^2}{2}) dt \tag{20a}$$

where q is the heat added to a unit mass particle from external sources. With assumptions 1) $\partial/\partial t(\ ) = 0$ and 4) $q = 0$, equations (20) and (20a) become:

$$\vec{W}dt\cdot\nabla (H_R) = 0 \tag{21}$$

$$\vec{V}dr\cdot\nabla (H) = 0 \tag{21a}$$

Equations (21) and (21a) indicate that for steady, adiabatic flow the relative total enthalpy is constant along any streamline. This does not mean that $\nabla (H_R) = 0$, since relative total enthalpy can assume different values for different streamlines.

Equation of continuity

Pressure ratios across a stage necessary to discharge a given flow rate are function of inlet Mach number, blade openings and the losses occurring in the blades. For an isentropic flow the mass flow rate passing thru a section dA_n perpendicular to the flow is given by:

$$d\,\dot{m}_{is} = \rho_{is}\, V_{is}\, dA_n \tag{22}$$

where ρ_{is} and V_{is} are respectively the density and the velocity corresponding to an isentropic process. It can be shown that equation (22) can be expressed for a perfect gas (see assumption 5) by:

$$d\,\dot{m}_{is} = \frac{P_T}{\sqrt{R_G\, T_T}}\, \Phi\, dA_n \tag{23}$$

where P_T, T_T are, respectively, total pressure and total temperature (constant for isoentropic and adiabatic flows) and Φ is a function of pressure ratio and gas isentropic exponent, namely:

$$\Phi = \sqrt{\frac{2\gamma}{\gamma-1}\left[\left(\frac{P}{P_T}\right)^{2/\gamma} - \left(\frac{P}{P_T}\right)^{\frac{\gamma+1}{\gamma}}\right]} \tag{24}$$

With the symbols in Fig. 3, assuming the pressure to be constant along the throat "a" equation (23) becomes:

$$d\,\dot{m}_{is} = \frac{P_T}{\sqrt{R_G\, T_T}}\, \Phi\, a \cos\lambda\, d\, r \tag{25}$$

Integrating equation (25) along the radius and for z blades the flow rate passing thru the stage is:

$$\dot{m}_{is} = z \int_{R_H}^{R_T} \frac{P_T}{\sqrt{R_G\, T_T}}\, \Phi\, a \cos\lambda\, dr \tag{26}$$

In actuality, the flow rate will be less than $\dot{m}_{is}$, because of the losses occurring in the blade channels.

A so-called restriction factor:

$$\xi = \frac{d\,\dot{m}}{d\,\dot{m}_{is}} \tag{27}$$

is now introduced.

In [5] the following relationship between ξ and the kinetic energy loss coefficient ζ^* is derived:

$$\xi = \frac{1}{1 + \zeta^* \frac{H}{K}} \tag{28}$$

where H and K are respectively the boundary layer wake form factor and the energy factor. For boundary layer profiles following the power law, the ratio $\frac{H}{K}$ can be expressed in power series:

$$\frac{H}{K} = \frac{1 - (1-Xe) \sum_{1}^{\infty} \left[Xe^{i-1}/1+(2i-1)m \right]}{(1-Xe) \sum_{1}^{\infty} i \left[Xe^{i-1}/1+(2i-1)m \right] - (1-Xe) \sum_{1}^{\infty} i \left[Xe^{i-1}/1+(2i+1)m \right]} \tag{29}$$

where:

$$Xe = 1 - (P/P_T)^{\gamma-1/\gamma} \tag{30}$$

and m is the exponent of the power law for the boundary layer profile (for incompressible flow, m depends on Reynolds number and varies between 1/7 and 1/10). Experience has shown that the loss coefficient ζ^* has to be taken less than the value ζ_{TOT} that corresponds to the overall energy losses that are given by the correlation methods. In the present program one of the three following different assumptions for ζ^* can be chosen: 1) $\zeta^* = \zeta_{TOT}$; 2) $\zeta^* = \frac{1}{2}\zeta_{TOT}$; 3) $\zeta^* = \zeta_{PROFILE}$.

While assumption 1) is certainly conservative, it is difficult to state which of assumptions 2) or 3) is the best one. Good agreement between experimental values and predicted flow rates for all considered turbines at low tip clearance values was found in [4], where assumption 2) was adopted. Assumption 3) was however found in closer agreement with test data for large values of rotor tip clearances.

Tip leakage flow rate will be calculated by using the relation:

$$\dot{m}_{CL} = \frac{1}{K_{CL}} \left(\xi \frac{P_T}{\sqrt{R\ T_T}} \Phi \cos\lambda\right)_{TIP} A_{CL} \tag{31}$$

where: $$A_{CL} = 2\pi\ R_H\ c\ell \tag{32}$$

Since the flow is not perpendicular to the leakage area, and since the restriction factor ξ_{TIP} does not account for boundary layer blockage occurring on shroud, the leakage flow rate must be divided by a coefficient K_{CL} (larger than 1), assumed equal to 2 in the present program.

With equations (29) and (33), the overall flow rate passing thru a blade row is given by:

$$\dot{m}_{TOT} = \dot{m} + \dot{m}_{CL} = z \int_{R_H}^{R_T} \xi \frac{P_T}{\sqrt{R_G\ T_T}} \Phi\ a \cos\lambda\ dr + \frac{1}{K_{CL}} \left(\xi \frac{P_T}{\sqrt{R\ T_T}} \Phi \cos\lambda\right)_{TIP} A_{CL} \tag{33}$$

Equation (33) can be expressed in the following dimensionless form:

$$\dot{m} = z\ R_m\ a_m \int_{x_H}^{x_T} \left(\xi \frac{P_T}{\sqrt{R_G\ T_T}} \Phi\ \bar{a} \cos\lambda\right)_x dx + \frac{2\pi}{K_{CL}} \xi_{TIP} \frac{x_T}{x_m} \frac{c\ell}{z\bar{a}} \left(\frac{P_T}{\sqrt{R\ T_T}} \Phi \cos\lambda\right)_{TIP} \tag{34}$$

where $$\bar{a} = \frac{a}{a_m} \tag{35}$$

METHOD OF SOLUTION

Since no direct solution of governing equations is possible, an iterative method is followed. At first, solutions are found without considering the influence of streamline curvature and slope. The derived radial shifts are then used for the second and final cycles of calculation. In Fig. 4 the scheme followed in the computer program is indicated. The names in brackets correspond to the names of the subroutines which perform the operations described next to the brackets.

The flow ahead of the stator is supposed to be uniform, so that the radii of streamlines dividing the flow rate in equal parts can be easily computed. For stator and rotor rows the following functions are supposed to be known:

STATOR	ROTOR
$\alpha_1 = \alpha_1$ (r, flow condition)	$\beta_2 = \beta_2$ (r, flow condition)
$a_1 = a_1$ (r)	$a_2 = a_2$ (r)
$\zeta_S = \zeta_S$ (r, flow condition)	$\zeta_R = \zeta_R$ (r, flow condition)

All derivatives used in the following analysis are computed by finite difference methods. The computer program calculates flow conditions along 5 streamlines. However the same scheme of calculation can be applied to any number of streamlines. By assuming the inlet Mach number M_o, the flow rate passing thru section 0 can easily be determined. Radial position of streamlines at station 1, R_1, and the axial velocity at mean streamline, V_{A1m}, are also assumed a priori, and will be checked later.

For any given values of V_{A1m}, ΔR, and δr, equation (18a) can be solved by iteration. In fact it can be reduced to:

$$\frac{d(\ell n\, Y^2)}{dx} = I\,(x) \qquad (36)$$

Equation (36) integrated, with boundary condition $\begin{cases} x = 1 \\ y = 1 \end{cases}$ (37)

gives:

$$\ln Y^2 = \int_1^x I\, dx \qquad (38)$$

and

$$Y = e^{\frac{1}{2} \int_1^x I\, d\, x} \qquad (39)$$

Solutions are found by trial and error, assuming approximate values of Y(x) and verifying equation (39). Once equation (39) has been solved, all flow conditions at station (1) are known and the overall continuity equation (34) can be solved. If the calculated flow rate is different from the assumed one, V_{am1} will be changed and the iteration shown in Fig. 4 is performed. When overall continuity equation is satisfied, the assumed radial position of streamlines is checked, and necessary iterations are performed. If streamlines continuity is met also, the flow at the rotor inlet is known completely. A similar iterative method is then followed for station 2 after the rotor as indicated in Fig. 4. If the flow after the rotor is known also, the radial shift of the streamlines can be determined, and the whole calculating procedure is repeated by taking account of the streamlines curvatures and the slopes in solving the equation of motion.

Eventually the resulting average pressure ratio across the turbine is compared with the desired one , and if the difference is larger than a smallprefixed error, the complete calculating scheme is repeated again with a new value of inlet Mach number. After the specified pressure ratio has been obtained, all output information is calculated and printed.

FLOW ANGLES AND LOSS COEFFICIENTS CORRELATIONS

Evidently, even the most accurate method of performance prediction will give results in disagreement with actuality, if the flow angles and/or the losses in the blade rows are not predicted with the necessary accuracy.

Several correlations, either empirical or theoretical, have been proposed in the technical literature. A comparative study of five correlations methods available in the present program can be found in Reference [4]. The purpose of the present chapter is not to discuss the applicability of these different correlations, but only to indicate the problems which arose, in applying the different correlation methods. In Fig. 5 the nomenclature and sign convection of the velocity triangles is indicated. Unless otherwise stated, the variables are positive if directed as in Fig. 5. In Fig. 6 the blading geometry characteristics used in the different correlation methods are indicated. The names given in Fig. 6 are the FORTRAN names used in the program for stator quantities at the mean radius.

The program is organized in such a way that other than considered flow angles and loss coefficients correlations can be introduced by adding a few cards and pertinent subroutines. Since the solution method is iterative, added subroutines can use blading and flow characteristics that are not used in the present program.

a) Flow angles correlations

Two methods, one given by Ainley and Mathieson [6] and the other given by Traupel [10] are available in subroutines. In both these methods, exit flow angles (α_1, β_2) are considered to be independent on inlet angles (α_0, β_1). While in Traupel's method the angles are a function of blading geometry only, in A&M method also the exit Mach number is supposed to affect the angles. Although both these methods are given for a "reference diameter approach", they will be applied in three-dimensional calculations with the assumption that at any radius the angle is related only to the corresponding characteristics. Since during the calculations both Mach numbers and streamlines radii will be changed, flow angles corrections are automatically performed during the solution of the equation of motion.

b) Loss coefficients correlations

The assumption is made that at any particular radius the loss coefficient is a function of the characteristics at that radius only. It is realized that this assumption is not realistic, since secondary and leakage losses are certainly not equally distributed along the radius. On the other hand, secondary and tip leakage flows are not understood well enough at the present time to formulate any other reasonable assumption.

Five loss correlation methods given in Ref. [6-10] are available in subroutines. They calculate loss coefficients from given blade geometry and flow angles and velocities.

The first considered method is the Ainley and Mathieson [6] method. Recently an improvement to the original method was given by Dunham and Came [7]. Both methods are available in subroutines. These methods express losses by total pressure loss coefficient Y, defined by:

$$Y = \frac{P_{To} - P_t}{P_t - p} \tag{40}$$

and assume Y to be independent on pressure ratio P_{To}/p. The relationship between the kinetic energy loss coefficient ζ and Y is given by:

$$\zeta = \frac{\left[\frac{1+Y}{1+Y\, p/P_{To}}\right]^{\frac{\gamma-1}{\gamma}} - 1}{\left(\frac{1}{p/P_{To}}\right)^{\frac{\gamma-1}{\gamma}} - 1} \tag{41}$$

The assumption that Y is constant implies that ζ decreases with increasing Mach number. Since this behavior is not experimentally proved, two alternatives to equation (41) are available in the program. In both these alternatives ζ is supposed to be constant with pressure ratio, and assumes respectively the value corresponding to very low Mach numbers (eq. 42) or to an exit Mach number of 0.8 (eq. 43).

$$\zeta = \zeta_o = \lim_{p/P_{To} \to 1} \zeta = \frac{Y}{1+Y} \tag{42}$$

$$\zeta = \zeta_{M=.8} = \frac{\left[\frac{1+Y}{1+Y \cdot \beta^*}\right]^{\frac{\gamma-1}{\gamma}} -1}{(1/\beta^*)^{\frac{\gamma-1}{\gamma}} -1} \tag{43}$$

where β^* is the pressure ratio corresponding to an isentropic Mach number of 0.8, given by:

$$\beta^* = [1 + \frac{\gamma-1}{2} \times .8^2]^{-\frac{\gamma}{\gamma-1}} \tag{44}$$

The same alternatives are given also for the simple method of Lenherr and Carter [9].

For the method of Balje' [8], the boundary layer wake form factor H must be introduced.

With the same nomenclature and assumptions as in eq. (29), H can be expressed by:

$$H = \frac{1 - (1-X_e) \sum_1^\infty i \left(\frac{X_e^{i-1}}{1+m\,(2i-1)} \right)}{- (1-X_e) \sum_1^\infty i \left(\frac{X_e^{i-1}}{1+m(2i)} \right) + (1-X_e) \sum_1^\infty i \left(\frac{X_e^{i-1}}{1+m(2i-1)} \right)} \qquad (45)$$

In this program the assumption m = 0.15 is made. If another exponent has to be introduced, card #17 must be changed in the MAIN routine.

In Traupel's method, the loss coefficients depend on the coefficient:

$$X_p = X_p \text{ (Re, relative surface roughness, turbulence factor).} \qquad (46)$$

In the present program, the standard value of $X_p=1$ is assumed. If the considered turbine has peculiar values of surface roughness or Reynolds numbers, it will be necessary to change card #15 in the MAIN routine.

For conformity with the other methods, tip clearance losses are expressed by the kinetic energy loss coefficient ζ_{CL}, instead of by the overall efficiency decrease $\Delta\eta_{CL}$ as in [10]. The relationship between $\Delta\eta_{CL}$ and ζ_{CL} is given by:

$$\zeta_{CL} = (1-\zeta_r) \times \left[1 - \left(1 - \frac{\Delta h_{is}\, \Delta\eta_{CL}}{u_2\, W_{w2}}\right)^2 \right] \qquad (47)$$

where Δh_{is} is the isentropic enthalpy drop through the turbine and ζ_r is the rotor kinetic energy loss coefficient for zero tip clearance.

The present computer program is composed of a MAIN routine and 28 subroutines, eight of which are concerned with flow calculations, two with flow angle correlations, 15 with blade loss correlations, and three with numerical interpolations. A brief description of the purpose of each routine is given below.

a) <u>MAIN routine</u>

1. The primary function of the MAIN routine is to control the overall logic of the computer program which is indicated in Fig. 4. Furthermore the imput data are read, numerical constants are introduced, interpolations concerning stall and blade angles and flow areas are performed and the flow angles are computed. Eventually, also the output data are printed.

b) <u>Flow calculation subroutines</u>

2. In subroutine CHAN the flow rate passing through the section 0 is calculated from the conditions ahead of the stator.

3. In subroutine STATØR the equation of motion (18a) is solved, and the flow conditions after the stator are calculated. If necessary, new values of the flow angles are also calculated.

4. In subroutine RØTØR1 the absolute flow properties calculated in STATØR are converted into relative properties at rotor inlet.

5. In subroutine RØTØR2 the equation of motion (18) is solved, and the flow conditions after the stator are calculated. If necessary, also new values of flow angles are calculated.

6. In subroutine FLØWR the flow rate passing through the blade sections, either at station 1 or 2, is computed by equation (34), and compared with the value calculated in CHAN. If the difference is larger than a small prefixed error, a new value of the axial velocity at the mean stremaline is computed. The fractional values of the flow rate passing between the hub and each streamline are calculated also.

7. In subroutine SLINE the fractional values of the flow rate computed in FLØWR are compared with prefixed ones. If the differences are larger than a small specified error, new values of the streamline radii, either at station 1 or 2, are computed.

8. In subroutine ALØS1 the stator loss coefficients are calculated from the chosen loss correlation, as a function of blading geometry and flow characteristics. Coefficients ζ^* of (28) are computed for the stator blades.

9. In subroutine ALØS2 the rotor loss coefficients are calculated from the chosen loss correlation as function of blading geometry and flow characteristics. Coefficients ζ^* of equation (28) are computed for the rotor blades.

c) <u>Flow Angles Subroutines</u>

10. In subroutine ANGAIN the flow angles are computed from blading geometry and exit Mach numbers with the method of Ainley and Mathieson [6].

11. In subroutine ANGTRA the flow angles are computed from blading geometry with Traupel's method [10].

d) <u>Loss Correlation Subroutines</u>

The six subroutines given below are concerned with the methods [6] and [7].

11. In subroutine CØEFFI the imput cards concerning the profile losses of nozzle blades given in [6] are read, and the necessary interpolations are performed.

12. In subroutine CØEFF2 a similar process is followed for the profile losses of impulse blades.

13. In subroutine CALYAØ the profile losses of nozzle blades are calculated with the coefficients computed in CØEFFI.

14. In subroutine CALYA2 the profile losses of impulse blades are calculated with the coefficients computed in CØEFF2 .

15. In subroutine FIG6 the necessary interpolations for calculating the secondary losses are performed.

16. In subroutine AINLØS the overall loss coefficients with either method [6] or [7] are calculated from blading geometry and flow angles. Subroutine AINLØS must be called after subroutines CØEFFI and CØEFF2, and calls subroutines CALYAØ, CALYA2 and FIG6.

The eight subroutines given below are concerned with method (11) of the loss correlation.

17. In subroutine TRAUP1 the imput cards concerning the profile losses given by Traupel's method are read, and the necessary interpolations are performed.

18. In subroutine XPØ the basic profile loss coefficients are computed with the coefficients calculated in TRAUP1.

19. In subroutine CSIM Mach number effects on the loss coefficients are computed.

20. In subroutine CID the effects due to the trailing edge thichness and nontwisted blades on the loss coefficients are computed.

21. In subroutine CSIW the end wall loss coefficients are computed.

22. In subroutine CSIR the secondary loss coefficients are computed.

23. In subroutine ALEAK the tip leakage efficiency losses are computed.

24. In subroutine TRAUP2 the overall loss coefficients are computed with Traupel's method [10] from both blade geometry and flow characteristics. Subroutine TRAUP2 has to be called after TRAUP1, and calls subroutines XPØ, CSIM, CID, CSIW, CSIR and ALEAK.

25. In subroutine ZALLØS the overall loss coefficients are computed with the method of Lenherr and Carter [9] from the flow angles and the relative velocities.

26. In subroutine BALJE the overall loss coefficients are computed with Balje's method [8] from blade geometry and flow conditions.

e) Numerical Interpolation Subroutines

27. In subroutine PARAB the coefficients of the parabolic interpolations used to approximate curves are calculated.

28. In subroutine CHBFT the coefficients of the polinomial of arbitrary degree, which is the best fit of a given array of points in the Chebyschev sense, are calculated.

29. In subroutine YC the value of the polynomial determined in CHBFT, corresponding to a given value of the independent variable, is calculated.

Description of Imput Data

The imput data of the present computer program consist of 63 + NSETS cards, NSETS being the number of conditions for which performance values are to be obtained. They can be divided in three sections. In the first, the constant values used in the methods of Ainley and Mathieson and of Traupel are introduced (these 36 cards are read respectively in subroutines CØEFFI, CØEFF2 and TRAUP1). In the second, the specifications about the detail of output desired, the tolerances of the numerical solutions, the systems of correlation of the flow angles and the loss coefficients, the coefficients used in the equation of continuity, the gas properties and the turbine geometry are stated. In the third, the conditions for which performance values are to be found are introduced.

The 36 input cards for the first section are given in Table I. They will remain unchanged for all turbines. Detailed description of the 27 cards composing the second section of the imput are given in Table II, where also a description of the third imput section can be found in cards #28 and #29. An example of the imput cards described in Table II is given in Table III.

Description of the normal output

In Table IV the output corresponding to the imput of Tables I and III is given. It can be seen that it consists of 1 + 3 NSETS sheets. In the first sheet the turbine geometrical dimensions and the choice among the different correlation methods are described. Then three sheets for every set of operating conditions are printed. The first of these sheets describes the flow conditions at station 1 after the stator row; the second one the flow conditions after the rotor row; and the third one gives the main overall turbine characteristics and the mass averaged performance values.

ACKNOWLEDGEMENTS

The author would like to express his appreciation to Dr. M. H. Vavra for providing guidance and counsel during the investigation.

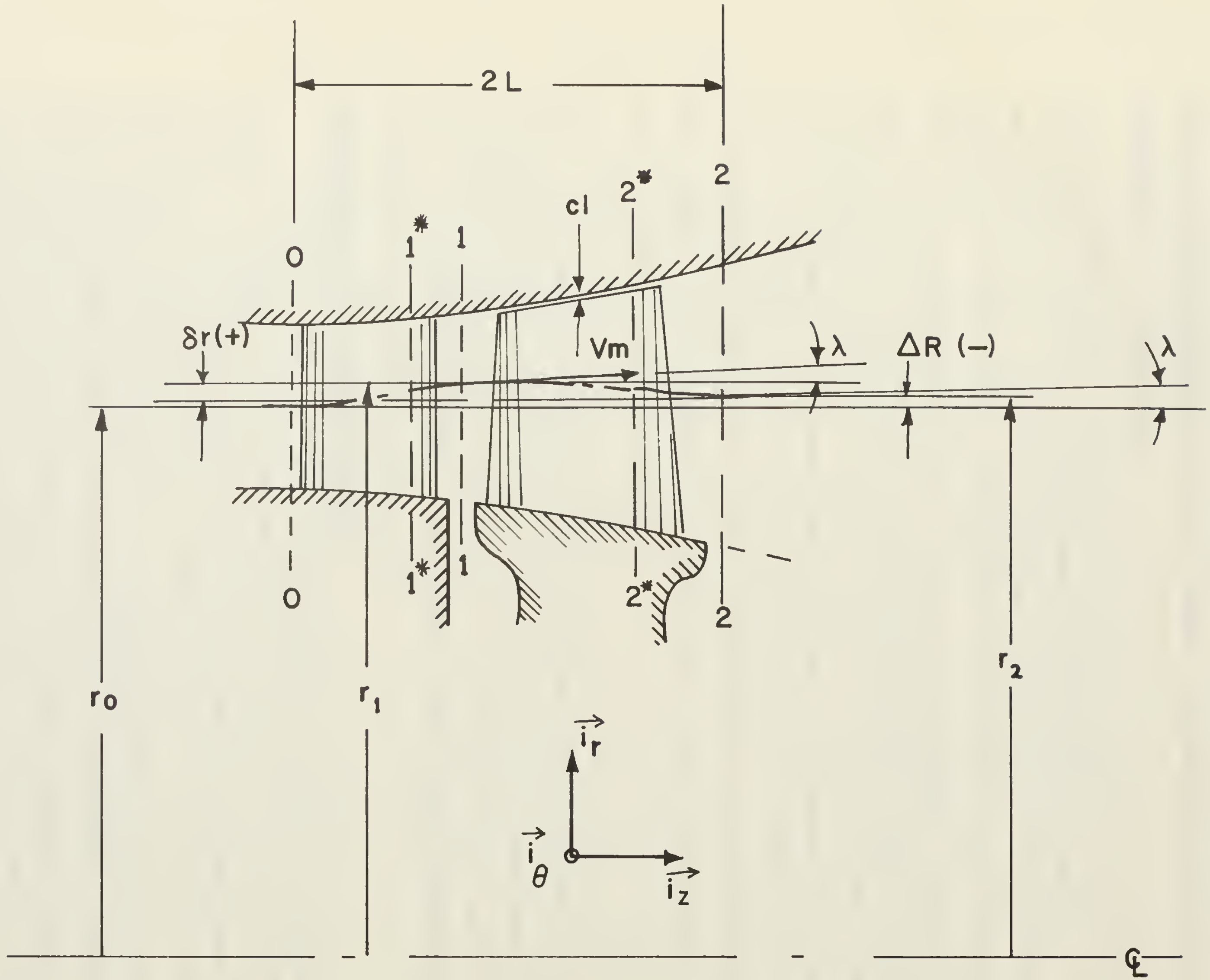


Fig. I Coordinates, stations and streamline nomenclature.

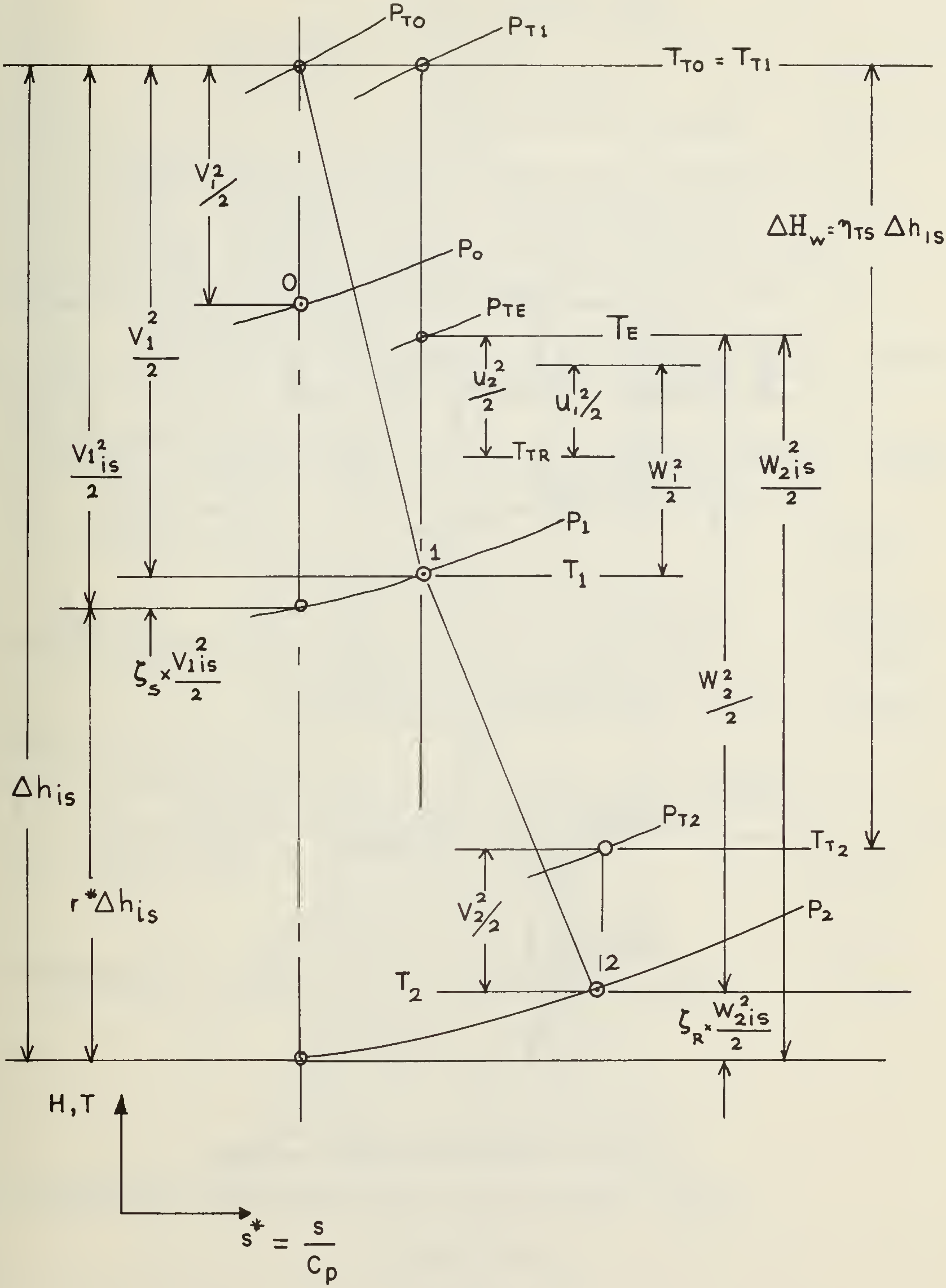


Fig. 2— Turbine thermodynamic process.

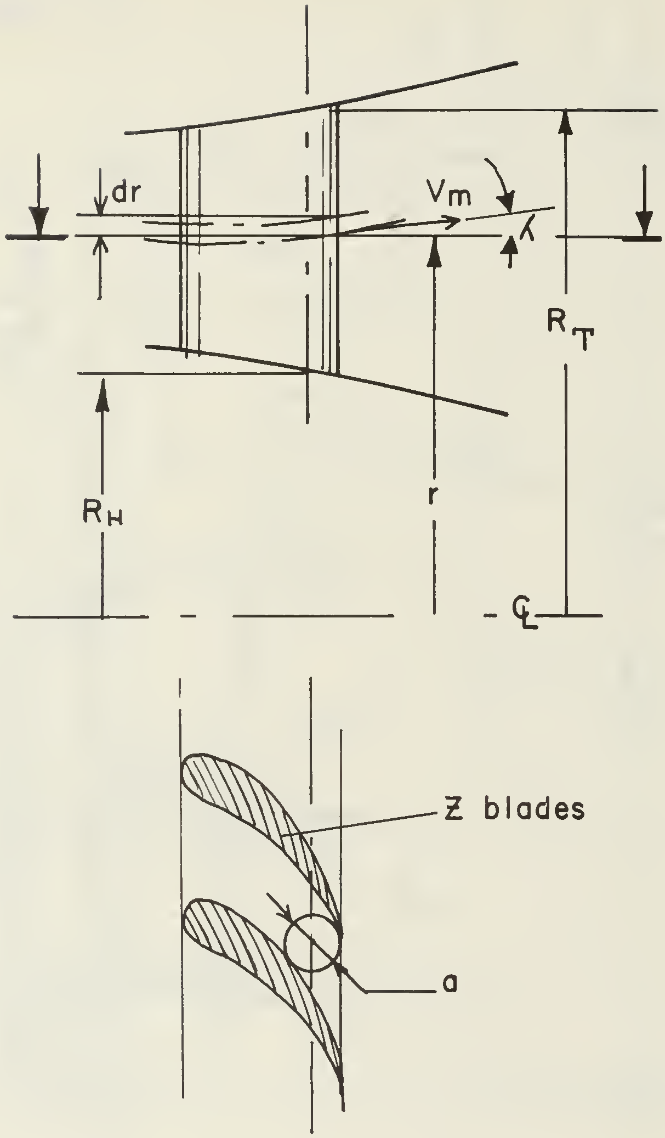


Fig. 3 Symbols in continuity equation.

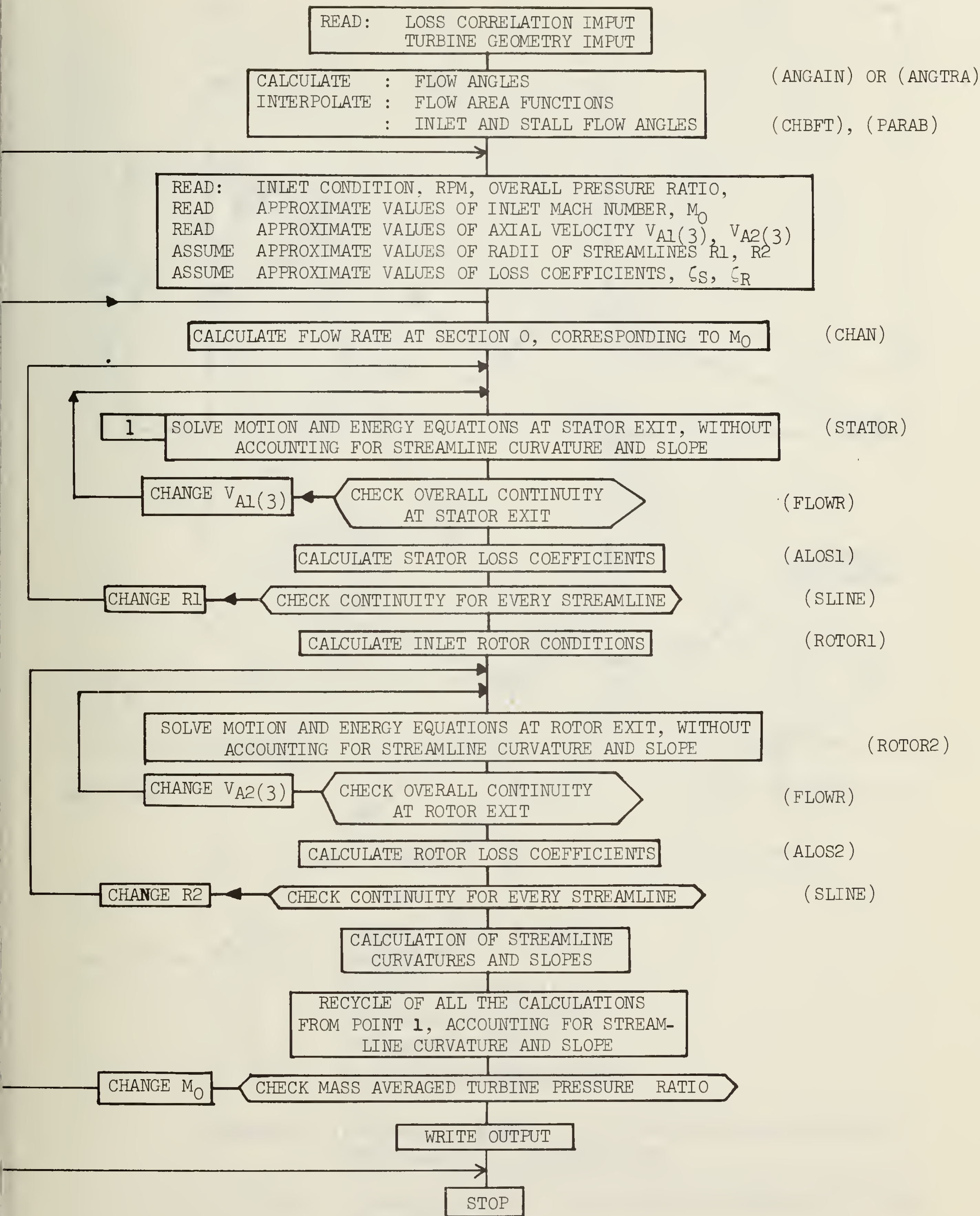


Fig. 4 Flow diagram

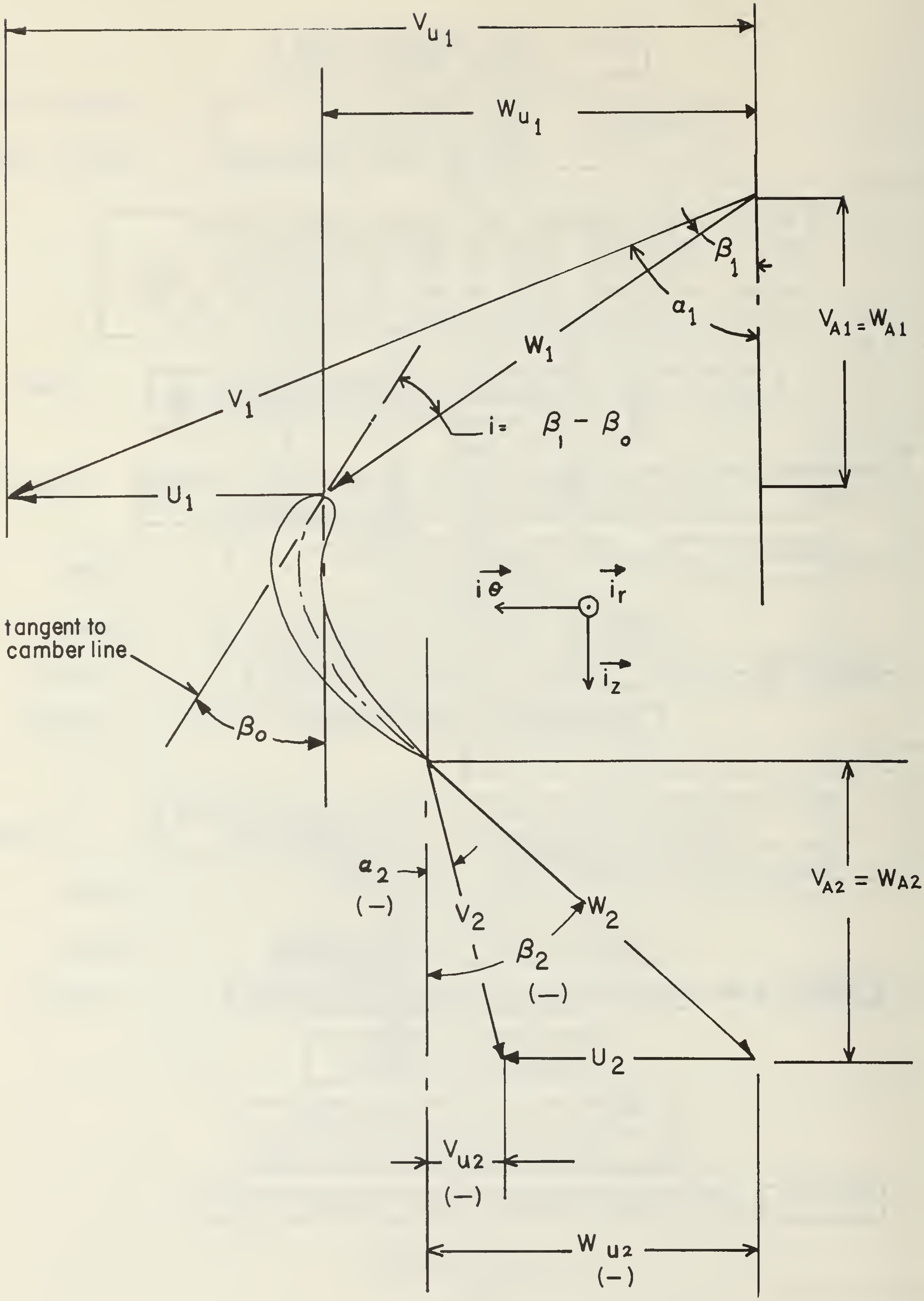
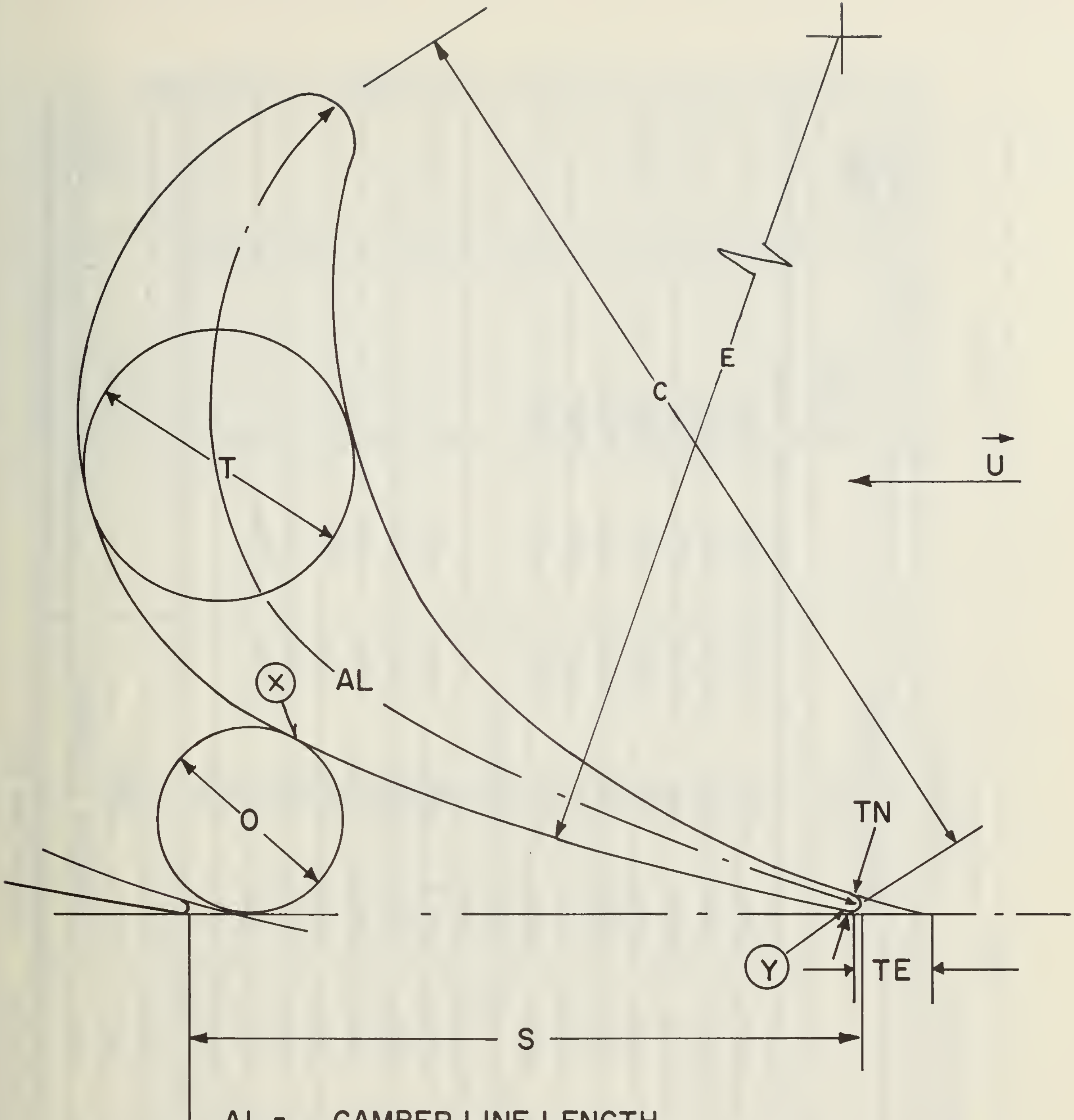


Fig.5 Velocity diagrams



AL = CAMBER LINE LENGTH
C = CHORD
O = THROAT DIAMETER
E = CURVATURE RADIUS
S = SPACING
T = MAXIMUM THICKNESS

TE = TRAILING EDGE THICKNESS PROJECTED IN PERIPHERAL DIRECTION

TN = TRAILING EDGE THICKNESS, NORMAL TO FLOW DIRECTION

Fig.6 Blade geomety nomenclature

PROGRAMMER E. MACCHI

PROGRAM AXIAL TURBINES

DATE AUG. 1970

PAGE 1 OF 2

SPECIAL INSTRUCTIONS FIXED IMPUT DATA

CARD PUNCH OPERATOR

DATE COMPLETED

SUBMIT FOR PROCESSING ☐ YES ☐ NO

FORTRAN STATEMENT

O = ZERO, Ø = ALPHA O; I = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z

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   .0633   .049   .0377   .028   .022  .0200    .018    .017  .018
   .0644   .051   .0400   .030   .024  .0222    .021    .020  .022
   .0655   .053   .0411   .032   .027  .0244    .024    .027  .034
   .0677   .054   .0433   .035   .030  .0299    .030    .034  .042
   .0688   .056   .0455   .039   .037  .0399    .042    .048  .056
   .0700   .057   .0511   .048   .048  .0511    .053    .060  .070
   .0733   .063   .0599   .057   .060  .0644    .071    .080  .093
  .30   .40   .50   .60   .70   .80   .90  1.00  1.10
 40.   50.   60.   65.   70.   75.   80.
   .1400   .108   .0877   .075   .068  .0677    .070    .076
   .1422   .112   .0922   .080   .075  .0766    .081    .088
   .1455   .115   .0988   .088   .085  .0888    .094    .104
   .1488   .118   .1066   .102   .103  .1088    .116    .125
   .1566   .131   .1199   .115   .121  .1288    .140    .152
   .1622   .142   .1366   .140   .149  .1622    .176    .192
  .30   .40   .50   .60   .70   .80   .90  1.00
 40.   50.   55.   60.   65.   70.
  .0570   .0465  .0440  .0428  .0424
  .0424   .0422  .0420  .0402  .0313  .0000
  .0530   .0415  .0350  .0330  .0323
```

EIGHTY COLUMN FORTRAN CODING SHEET 12ND PGS 5220/1 (11-66)

TABLE I (1)

PROGRAMMER	PROGRAM	DATE
E. MACCHI	AXIAL TURBINES	AUG. 1970

PAGE 2 OF 2 — SPECIAL INSTRUCTIONS: FIXED INPUT DATA

CARD PUNCH OPERATOR — DATE COMPLETED — SUBMIT FOR PROCESSING ☐ YES ☐ NO

FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z)

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 .04955   .0380   .0312    .0296   .0285
 .02833   .0280   .02755   .0250   .0143   .00000
 .04755   .0355   .02955   .0267   .0250
 .02500   .0246   .02422   .0208   .0070   .00000
 .04400   .0335   .02733   .0245   .0225
 .02255   .0216   .02033   .0168   .0000   .00000
 .04200   .0312   .02244   .0205   .0183
 .01833   .0170   .01544   .0106   .0100   .00000
 .04200   .0300   .02113   .0181   .0152
 .01500   .0136   .01044   .0050  -.0150
 .04200   .0300   .02066   .0155   .0125
 .01255   .0093   .00733   .0000  -.0200
10.   15.  20.  25.  30.  40.  50.  60.
 40.   50.   60.   70.   80.
 80.   90.  100.  120.  150.  170.
```

EIGHTY COLUMN FORTRAN CODING SHEET 12ND PGS 5220/1 (11-66)

TABLE I (2)

CARD	FORTRAN NAME	FORMAT	DESCRIPTION	COMMENTS
1	IND INZ IWR	I 5 I 5 I 5	PRINT INDEX PRINT INDEX PRINT INDEX	SEE TABLE IV
2	ICØR IAI IAN ICL IINC ICØZ ICØN	I 5 I 5 I 5 I 5 I 5 I 5 I 5	LOSS INDEX LOSS INDEX ANGLE INDEX CLEARANCE INDEX LOSS INDEX LOSS INDEX CONTINUITY INDEX	SEE TABLE V
3	VIS2 VIS3 CP EMME GAM	E 12.3 E 12.3 F 10.4 F 10.4 F 10.4	VISCOSITY AT STATION 1 VISCOSITY AT STATION 2 SPECIFIC HEAT AT P=CONST MOLECULAR MASS ISOENTROPIC EXPONENT	(LB/SEC-FT) (LB/SEC-FT) (BTU/LB-DEG. F)
4	TIPC ZS ZR	F 8.4 F 8.4 F 8.4	ROTOR TIP CLEARANCE STATOR NUMBER OF BLADES ROTOR NUMBER OF BLADES	(INCHES)
5	CV CK	F 8.4 F 8.4	AXIAL DISTANCE BETWEEN STATIONS CURVATURE FACTOR	SEE EQ. (16) AND (17) SEE EQ. (16)
7	STALI (I), I=1,10	10F 5.2	ROTOR STALL ANGLES AT 10 RADII EQUALLY SPACED FROM HUB TO TIP	DEFINED BY AINLEY METHOD [6]
6	BETAØ(I) I=1,5,2	3F 8.4	ROTOR BLADE ANGLES, AT HUB, MEAN AND TIP SECTIONS	DEFINED BY THE TANGENT CAMBER LINE SEE FIG. 6

TABLE II (1)

CARD	FORTRAN NAME	FORMAT	DESCRIPTION	COMMENTS
8	A1 (I), I=1,5	5F8.4	STATOR BLADE OPENINGS AT FIRST FIVE RADII OF CARD 7	(INCHES)
9	A1((I), I=6,10	5F8.4	SAME AS CARD 8, AT SECOND FIVE RADII OF CARD 7	(INCHES)
10	A2 (I), I=1,5	5F8.4	SAME AS CARD 8, FOR ROTOR BLADE	(INCHES)
11	A2 (I), I=6,10	5F8.4	SAME AS CARD 9, FOR ROTOR BLADE	(INCHES)
12	AL ALI ALØ	F8.5 F8.5 F8.5	STATOR BLADE CAMBER LINE LENGTH, MEAN SECTION STATOR BLADE CAMBER LINE LENGTH, HUB SECTION STATOR BLADE CAMBER LINE LENGTH, TIP SECTION	SEE FIG. 6 (INCHES)
13	C CI CØ	F8.5 F8.5 F8.5	STATOR BLADE CHORD, MEAN SECTION STATOR BLADE CHORD, HUB SECTION STATOR BLADE CHORD, TIP SECTION	SEE FIG. 6 (INCHES)
14	E EI EØ	F8.5 F8.5 F8.5	STATOR BLADE CURVATURE, MEAN SECTION STATOR BLADE CURVATURE, HUB SECTION STATOR BLADE CURVATURE, TIP SECTION	SEE FIG. 6 (INCHES)
15	T TI TØ	F8.5 F8.5 F8.5	STATOR BLADE MAXIMUM THICKNESS, MEAN SECTION STATOR BLADE MAXIMUM THICKNESS, HUB SECTION STATOR BLADE MAXIMUM THICKNESS, TIP SECTION	SEE FIG. 6 (INCHES)
16	TE TEI TEØ	F8.5 F8.5 F8.5	STATOR BLADE T.E. PROJECTED THICKNESS, MEAN SECTION STATOR BLADE T.E. PROJECTED THICKNESS, HUB SECTION STATOR BLADE T.E. PROJECTED THICKNESS, TIP SECTION	SEE FIG. 6 (INCHES)
17	TN TNI TNØ	F8.5 F8.5 F8.5	STATOR BLADE T.E. NORMAL THICKNESS, MEAN SECTION STATOR BLADE T.E. NORMAL THICKNESS, HUB SECTION STATOR BLADE T.E. NORMAL THICKNESS, TIP SECTION	SEE FIG. 6 (INCHES)

TABLE II (2)

CARD	FORTRAN NAME	FORMAT	DESCRIPTION	COMMENTS
18-23		F8.5	SAME OF CARDS 12-17, FOR ROTOR BLADE	(INCHES)
24	RC (1) RC (5)	F8.4 F8.4	HUB RADIUS AT STATION 0 TIP RADIUS AT STATION 0	(INCHES)
25	RS (1) RS (5)	F8.4 F8.4	HUB RADIUS AT STATION 1 HUB RADIUS AT STATION 1	(INCHES)
26	RR (1) RR (5)	F8.4 F8.4	HUB RADIUS AT STATION 2 TIP RADIUS AT STATION 2	(INCHES) WITHOUT TIP CLEARANCE
27	TØL1 TØL2 TØL3 TØL4	F8.4 F8.4 F8.4 F8.4	REL. TOLERANCE IN OVERALL CONTINUITY REL. TOLERANCE IN STREAMLINE CONTINUITY REL. TOLERANCE IN PRESSURE RATIO REL. TOLERANCE IN VELOCITY DISTRIBUTION	
28	NSETS	I5	NUMBER OF SETS OF OPERATING CONDITIONS FOR WHICH SOLUTIONS HAVE TO BE FOUND	
29 ÷ (28+NSETS)	AMC AMS PTØ TTØ AMR RPM PR VA1(3) VA2(3)	F8.4 F8.4 F8.4 F8.4 F8.4 F8.4 F8.4 F8.4 F8.4	MACH NUMBER AT STATION 0 MACH NUMBER AT STATION 1 TOTAL PRESSURE AT STATION 0 TOTAL TEMPERATURE AT STATION 0 MACH NUMBER AT STATION 2 SPEED OF REVOLUTION TOTAL-STATIC PRESSURE RATIO AXIAL VELOCITY AT MEAN STR. AT STATION 1 AXIAL VELOCITY AT MEAN STR. AT STATION 2	APPROXIMATE VALUE APPROXIMATE VALUE (PSI) ASSUMED TO BE CONSTANT (^{o}R) ASSUMED TO BE CONSTANT APPROXIMATE VALUE (REVOLUTION/MINUTE) MASS AVERAGED QUANTITY APPROXIMATE VALUE APPROXIMATE VALUE

TABLE II (3)

PROGRAMMER	PROGRAM	DATE
E. MACCHI	AXIAL TURBINES	AUG. 1970

PAGE	SPECIAL INSTRUCTIONS
1 OF 2	VARIABLE IMPUT DATA -

CARD PUNCH OPERATOR	DATE COMPLETED	SUBMIT FOR PROCESSING
		☐ YES ☐ NO

FORTRAN STATEMENT

0 = ZERO Ø = ALPHA O 1 = ONE I = ALPHA I 2 = TWO Ƶ = ALPHA Z

TYPE | STATEMENT NO. | CONT. | SERIAL NUMBER

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  .030   40.      76.
   2.5   5.
   .50.  43.   30.
 11.0 11.3 11.6 11.8 12.0 13.0 14.0 15.0 17.0 18.5
0.5252 0.5855 0.6459 0.7002 0.7665
0.8268 0.8881 0.9494 1.0108 1.0722
0.625  0.641  0.657  0.673  0.688
0.703  0.717  0.739  0.740  0.748
2.96      2.82      3.34
2.83      2.54      3.15
20.       20.       20.
0.33      0.33      0.36
0.063     0.074     0.056
0.025     0.025     0.025
2.47      2.46      2.50
2.16      2.13      2.16
8.0       5.30      8.0
```

PROGRAMMER E. MACCHI	PROGRAM AXIAL TURBINES	DATE AUG. 1970
PAGE 2 OF 2	SPECIAL INSTRUCTIONS VARIABLE IMPUT DATA	
CARD PUNCH OPERATOR	DATE COMPLETED	SUBMIT FOR PROCESSING ☐ YES ☐ NO

TYPE | STATEMENT NO. | CONT. | FORTRAN STATEMENT | SERIAL NUMBER

0 = ZERO Ø = ALPHA O | I = ONE I = ALPHA I | 2 = TWO Ƶ = ALPHA Z

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 0.38    0.384    0.25
 0.0435  0.046    0.0384
 0.030   0.030    0.030
  10.5    15.0
  10.5    15.0
  10.5    15.0
   0.001   0.001   0.001   0.001
    1
  .215   0.9     44.     550.0   0.7     3262.0  1.50   330.    330.
```

EIGHTY COLUMN FORTRAN CODING SHEET 12ND PGS 5220/1 (11-66)

TABLE III (2)

PRINT INDEX	POSSIBLE VALUES	SPECIFICATIONS
IND	1	Intermediate results are printed in subroutines CHAN, STATØR, RØTØR2, FLØWR, SLINE
	$\neq 1$	No intermediate prints.
INZ	1	Solutions are printed for all calculated pressure ratios
	$\neq 1$	Solutions are printed only for specified pressure ratios
IWR	1	Intermediate results in loss coefficients subroutines are printed
	$\neq 1$	No intermediate prints

TABLE IV

CORRELATION INDEX	POSSIBLE VALUES	SPECIFICATIONS
ICØR	1	A&M [6] or D&C [7] loss correlation method is adopted, depending on IAI value.
	2	Balje [8] loss correlation method is adopted.
	3	L&C [9] loss correlation method is adopted.
	4	Traupel [10] loss correlation method is adopted.
IAI	0	If ICOR=1, A&M [6] loss correlation method is adopted.
	1	If ICOR=1, D&C [7] loss correlation method is adopted.
IAN	1	A&M [6] flow angles correlation is adopted.
	2	Traupel [10] flow angles correlation is adopted.
ICL	0	Rotor is not shrouded.
	1	Rotor is shrouded.

TABLE V (1)

CORRELATION INDEX	POSSIBLE VALUES	SPECIFICATIONS
IINC	0	Loss coefficients are function of flow angles
	1	Loss coefficients are function of blade inlet angles, for negative incidence
IC∅Z	1	Loss coefficient $\zeta = \zeta_o$ (see eq. (42))
	6	Loss coefficient $\zeta = \zeta$ (Y, pressure ratio) (see eq. (41))
	8	Loss coefficient $\zeta = \zeta_{M=0.8}$ (see eq. (43))
IC∅N	1	Loss coefficient in continuity equation $\zeta^* = .5\ \zeta_{TOT}$
	2	Loss coefficient in continuity equation $\zeta^* = \zeta_{PROF}$
	3	Loss coefficient in continuity equation $\zeta^* = \zeta_{TOT}$

TABLE V (2)

TABLE VI

EXAMPLE OF NORMAL OUTPUT DATA

R1	A1	R2	A2
10.500	0.5252	10.500	0.6250
11.000	0.5855	11.000	0.6410
11.500	0.6459	11.500	0.6570
12.000	0.7002	12.000	0.6730
12.500	0.7665	12.500	0.6880
13.000	0.8268	13.000	0.7030
13.500	0.8881	13.500	0.7170
14.000	0.9494	14.000	0.7390
14.500	1.0108	14.500	0.7400
15.000	1.0722	15.000	0.7480

NUMBER OF STATOR BLADES = 40.
NUMBER OF ROTOR BLADES = 76.
ROTOR TIP CLEARANCE = 0.0300
AXIAL DISTANCE L = 2.50
CURVATURE FACTOR K = 5.00

BLADING GEOMETRY

	C	E	T	TE	TN	AL	R
STATOR	2.5400	20.0000	0.3300	0.0740	0.0250	2.8200	10.5000
	2.8300	20.0000	0.3300	0.0631	0.0250	2.9600	12.7500
	3.1500	20.0000	0.3600	0.0560	0.0250	3.3400	15.0000
ROTOR	2.1300	5.3000	0.3840	0.0460	0.0300	2.4600	10.5000
	2.1600	8.0000	0.3800	0.0435	0.0300	2.4700	12.7500
	2.1600	8.0000	0.2500	0.0384	0.0300	2.5000	15.0000

ALL DIMENSIONS INDICATED IN THIS TABLE ARE IN INCHES

CORRELATION SYSTEM
ICOR = 4
IAI = 0
IAN = 2
ICOZ = 1
IINC = 1
ICL = 0
ICON = 2

GAS PROPERTIES	CP (BTU/LB F)	MOLECULAR MASS	GAMMA	VISCOSITY (1) (LBM /SEC FT)	VISCOSITY (2) (LBM /SEC FT)
	0.240	28.970	1.400	0.130E-04	0.120E-04

SET NUMBER	PAGE NUMBER	RPM	TOTAL/STATIC PRESSURE RATIO	INLET TOTAL PRESSURE (PSI)	INLET TOTAL TEMPERATURE (DEG. R)
1	1	3262.0	1.500	44.000	550.00

STATOR EXIT SOLUTION

STREAM LINE	RADIAL POSITION (IN)	X=R/RM	RADIAL SHIFT (IN)	BLADE OPENING (IN)	Y=VA/VAM	BLADE EFFICIENCY	LOSS COEFFICIENT	ZETA* CONTINUITY	FLOW RATE FRACTION
1	10.500	0.802	0.0	0.5240	0.9172	0.9203	0.0797	0.0366	0.0
2	11.917	0.911	-0.1301	0.6920	0.9642	0.9215	0.0785	0.0352	0.2491
3	13.085	1.000	-0.1379	0.8286	1.0000	0.9224	0.0776	0.0342	0.5001
4	14.095	1.077	-0.0838	0.9569	1.0200	0.9229	0.0771	0.0331	0.7501
5	15.000	1.146	0.0	1.0733	1.0296	0.9233	0.0767	0.0324	1.0000

STREAM LINE	ABSOLUTE VELOCITY (FPS) AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	RELATIVE VELOCITY (FPS) AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	WHEEL VELOCITY
1	296.13	0.0	876.67	925.33	296.13	0.0	577.77	649.24	298.90
2	311.30	3.73	780.22	840.04	311.30	3.73	440.97	539.80	339.24
3	322.87	4.06	721.50	790.46	322.87	4.06	349.02	475.48	372.48
4	329.32	3.23	682.88	758.14	329.32	3.23	281.65	433.34	401.23
5	332.41	0.0	646.46	726.91	332.41	0.0	219.46	398.32	427.00

STREAM LINE	MACH NUMBER ABSOLUTE	RELATIVE	FLOW ANGLE (DEG) ABSOLUTE	RELATIVE	TEMPERATURE (DEG. R) TOTAL	STATIC	PRESSURE (PSI) TOTAL	STATIC	PRESSURE RATIO TOT/TOT	TOT/STA
1	0.86	0.61	71.34	62.87	550.00	478.75	42.048	25.874	1.0464	1.7006
2	0.77	0.50	68.25	54.78	550.00	491.28	42.453	28.595	1.0364	1.5387
3	0.72	0.43	65.90	47.23	550.00	498.01	42.662	30.137	1.0314	1.4600
4	0.69	0.39	64.26	40.54	550.00	502.17	42.786	31.118	1.0284	1.4140
5	0.66	0.36	62.79	33.44	550.00	506.03	42.898	32.047	1.0257	1.3730

SET NUMBER	PAGE NUMBER	RPM	TOTAL/STATIC PRESSURE RATIO	INLET TOTAL PRESSURE (PSI)	INLET TOTAL TEMPERATURE (DEG. R)
1	2	3262.0	1.500	44.000	550.00

ROTOR EXIT SOLUTION

STREAM LINE	RADIAL POSITION	X=R/RM	RADIAL SHIFT	BLADE OPENING	Y=VA/VAM	BLADE EFFICIENCY	LOSS COEFFICIENT	ZETA* CONTINUITY	FLOW RATE FRACTION
1	10.500	0.811	0.0	0.6251	1.0222	0.8277	0.1723	0.0879	0.0
2	11.785	0.911	-0.0599	0.6662	1.0312	0.8562	0.1438	0.0641	0.2505
3	12.940	1.000	-0.0628	0.7006	1.0000	0.8729	0.1271	0.0502	0.5004
4	14.017	1.083	-0.0490	0.7274	0.9749	0.8846	0.1154	0.0419	0.7505
5	15.000	1.159	0.0	0.7479	0.9680	0.8924	0.1076	0.0363	1.0000

	ABSOLUTE VELOCITY (FPS)				RELATIVE VELOCITY (FPS)				
STREAM LINE	AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	WHEEL VELOCITY
1	328.25	0.0	-0.30	328.25	328.25	0.0	-299.20	444.15	298.90
2	331.14	3.97	-0.46	331.16	331.14	3.97	-335.93	471.72	335.47
3	321.13	4.04	10.51	321.33	321.13	4.04	-357.83	480.82	368.34
4	313.07	3.07	22.43	313.88	313.07	3.07	-376.59	489.74	399.02
5	310.86	0.0	25.66	311.92	310.86	0.0	-401.34	507.65	427.00

	MACH NUMBER		FLOW ANGLE (DEG)		TEMPERATURE (DEG. R)		PRESSURE (PSI)		PRESSURE RATIO	
STREAM LINE	ABSOLUTE	RELATIVE	ABSOLUTE	RELATIVE	TOTAL	STATIC	TOTAL	STATIC	TOT/TOT	TOT/STA
1	0.30	0.41	-0.05	-42.35	506.38	497.41	30.736	28.873	1.4315	1.5239
2	0.30	0.43	-0.08	-45.42	505.92	496.90	31.002	29.109	1.4193	1.5116
3	0.29	0.44	1.87	-48.10	505.92	497.45	31.223	29.432	1.4092	1.4950
4	0.29	0.45	4.10	-50.27	505.89	497.77	31.352	29.626	1.4034	1.4852
5	0.29	0.46	4.72	-52.24	505.88	497.79	31.437	29.711	1.3996	1.4810

STREAM LINE	EQUIVALENT TEMPERATURE (DEG. R)	EQUIVALENT INLET PRESSURE (PSI)	EQUIV/STATIC PRESSURE RATIO	BLADE INLET ANGLE (DEG)	BLADE STALL ANGLE (DEG)	INCIDENCE ANGLE (DEG)
1	513.82	33.14	1.148	50.4	11.0	12.4
2	515.41	33.82	1.162	47.3	11.8	7.5
3	516.69	34.28	1.165	43.0	13.0	4.3
4	517.73	34.63	1.169	38.0	15.2	2.5
5	519.23	35.07	1.180	32.6	18.5	0.8

SET NUMBER	PAGE NUMBER	RPM	TOTAL/STATIC PRESSURE RATIO	INLET TOTAL PRESSURE (PSI)	INLET TOTAL TEMPERATURE (DEG. R)
1	3	3262.0	1.500	44.000	550.00

OVERALL TURBINE CHARACTERISTICS

STREAM LINE	PRESSURE RATIO TOT/STA	PRESSURE RATIO TOT/TOT	EFFICIENCY TOT/STA	EFFICIENCY TOT/TOT	HEAD COEFFICIENT	BLADE/JET SPEED RATIO	THEORETICAL DEGREE OF REACTION
1	1.5239	1.4315	0.6994	0.8142	8.3899	0.3452	-0.2412
2	1.5116	1.4193	0.7197	0.8418	6.3945	0.3955	-0.0405
3	1.4950	1.4092	0.7384	0.8585	5.1708	0.4398	0.0558
4	1.4852	1.4034	0.7505	0.8689	4.3874	0.4774	0.1182
5	1.4810	1.3996	0.7558	0.8757	3.8475	0.5098	0.1842

MASS AVERAGED QUANTITIES

HORSE POWER =	1954.03	(HP)
MOMENT =	3146.15	(FT-LB)
FLOW RATE =	130.69	(LB/SEC)
REFERRED RPM =	3166.91	
REFERRED HORSE POWER =	633.79	(HP)
REFERRED MOMENT =	1051.10	(FT-LB)
REFERRED FLOW RATE =	44.97	(LB/SEC)
TOTAL/STATIC EFFICIENCY =	0.7341	
TOTAL/TOTAL EFFICIENCY =	0.8535	
TOTAL/STATIC PRESSURE RATIO =	1.4985	
TOTAL/TOTAL PRESSURE RATIO =	1.4119	
HEAC COEFFICIENT =	5.5178	
BLACE/JET SPEED RATIO =	0.4257	
THECRETICAL DEGREE OF REACTION=	0.0262	
MACH NUMBER AT STATION 0 =	0.2162	

APPENDIX

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                C
                C      ANGLES CORRELATION INDECES
                C
                C      IAN=1 AINLEY   METHOD
                C      IAN=2 TRAUPEL  METHOD
                C
                C      LCSSES CORRELATION INDECES
                C
                C      ICOR=1  AYNLEY (IAI=0)  OR DUNHAM (IAI=1)
                C      ICOR=2  BALJE                METHOD
                C      ICOR=3  LENHERR   CARTER  METHOD
                C      ICOR=4  TRAUPEL   METHOD
                C      ICOZ=1  ZETA IS CONSTANT, EQUAL TO THE VALUE AT MACH=0
                C      ICOZ=6  Y IS CONSTANT, ZETA IS PRESSURE RATIO DEPENDENT
                C      ICOZ=8  ZETA IS CONSTANT,EQUAL TO THE VALUE AT MACH=0.8
                C      IINC=0  LOSSES ARE FUNCTION OF FLOW ANGLES
                C      IINC=1  LOSSES ARE FUNCTION OF BLADE ANGLES,FOR NEGATIVE INCIDENCE
                C      (FOR METHOD 4)
                C
                C      ICL=0  NOT SHROUDED ROTOR
                C      ICL=1  SHORUDED ROTOR
                C
                C      CONTINUITY EQUATICN CORRELATION
                C
                C      ICON=1   ZETAP=.5*(ZETA TOT)
                C      ICON=2   ZETAP=(ZETAP)
                C      ICON=3   ZETAP=ZETA
                C
                C
                C      PRINT  INDECES
                C
                C      IND=0   NO INTERMEDIATE WRITING
                C      IND=1      INTERMEDIATE WRITING
                C
                C      INZ=0   NO INTERMEDIATE WRITING FOR       DIFFERENT PRESSURE RATIOS
                C      INZ=1         INTERMEDIATE WRITING FOR  DIFFERENT PRESSURE RATIOS
                C      IWR=1 INTERMEDIATE PRINTS IN  LOSS  SUBROUTINES
                C
                C
0001                   DIMENSION ETAT(5), BETAT(5),TTIS(5)
0002                  0DIMENSION ALFAM(10),BETAM(10),RS(10),RR(10),ZETAR(10),ZETAPR(10),
                      1CALF(10),DBET(10),AS(10),AR(10),X1(10),X2(10),ALFA1(10),BETA2(10),
                      2T1(10),P1(10),V1(10),VA1(10),SI1(10),SI2(10),YS(10),S1(10),
                      3DSDX1(10),VU1(10),PRAT1(10),ZETAPS(10),WI1(10),VA2(10),WPER1(10),
                      4U(10),BETA1(10),HE(10),TTE(10),PTE(10),W1(10),WU1(10),DHEDX(10),
                      5DSDX2(10),WU2(10),W2(10),VU2(10),V2(10),YR(10),RI1(10),RI2(10),
                      6RI3(10),RI4(10),RI(10),SR1(10),SR2(10),YOLO(10),AA(10),SR(10),
                      7P2(10),T2(10),PRAT2(10),WPER2(10),DWDX(10),U2(10),T1IS(10),
                      8 T2IS(10),PRAT3(10),SS(10),ALFA2(10)
0003                  0DIMENSION DELH(10),TT2(10),PT2(10),PT1(10),T2S(10),
                      1ETAI(10),ETAS(10),PSIR(10),RSTAR(10),AKIS(10),ETAR(10),
                      2ALFA(10),BETA(10),AMS1(10),RC(10),DELR(10),WPERO(10),ZETAS(10),
                      3ZETAR1(20),ZETAR3(20),ZETAR5(20),BETAD(10),STALI(10)
0004                   DIMENSION R1(20),A1(20),B1(20),T10(20),ST1(20),IRR(20),R2(20),A2(2
                      10),B2(20),B6(20),RINC(20),DR(10),BETO(10),STALII(10),RINCI(10),AMR
                      22(10),ALFA22(10),BETA22(10),ALFA11(10),BETA11(10),ZETA1(10),AREA1(
                      310),AREA2(10),VR1(10),WR2(10)
0005                   DIMENSION AMW1(10),PRAT1T(10),OR1(10),BETET(10) ,AMV2(10)
0006                   COMMON /ABA/ BA17,BLEX
0007                   COMMON /CUR/ COSL(10)
0008                   CCMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0009                   COMMON /TR5/ TRA5
0010                   COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0011                   CCMMON /COZ/ ICCR,ICOZ,IINC,IAI,ICL,IAN,ICON
0012                    COMMON /MAC/ IN
0013                   CCMMON /IWI/ IND,INZ,IWR
0014                   COMMON /AUS/ XCL
0015                   COMMON /CSS/ CJ,G,C1
0016                   COMMON /AL1/  ALFA1,V1,TTO,RPM,RS,SI,TNI,H,O,CI,T1,P1,TO,TEI,ALI,
                      1BESP,XX,ANG2C,AMS1,S,TN,C,TE,AL,SO,TNO,CO,TEO,U ,O1I,D1O,O2I,D2O,
                      2ANG2I,ALFAX,TI,T,PTO,ALO,AMC
0017                   COMMCN /AL2/  BETA2,BETA1,BETAO,W2,TTE,U2,SIR,TNIR,HR,OZ,CIR,TIPC,
                      1SZ,TNR,CP,SOR,TNOR,COR,ALIR,ALR,ALOR,P2,WU2,W1    ,TEIR,TER,TEOR,
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                     201IR,DIOR,BETAZ,BETAI,ANM,TIR,TR,TOR,STALI,PTE,RS1,RS3,RS5,T2
0018                  TRA5=1.
0019                    XX=1.25
0020                  BLEX=0.15
0021                  IF(ICL.EQ.0)XCL=1.35
0022                  IF(ICL.EQ.1)XCL=.7
0023                   CALL COEFFI
0024                   CALL COEFF2
0025                  CALL TRAUP1
0026            3301  FORMAT(3F8.5)
0027               3  FORMAT(5F8.4)
0028               1  FORMAT(5F8.4)
0029             784  FORMAT(10F5.2)
0030             783   FORMAT(2F8.4)
0031            3340    FORMAT(2E12.3,3F10.4)
0032            3403    FORMAT(//3E20.4)
0033               2  FORMAT(3F8.4)
0034                  READ(5,4) INO,INZ,IWR
0035                  READ(5,4) ICOR,IAI,IAN,ICL,IINC,ICOZ,ICON
0036                  READ(5,3340)VIS2,VIS3,CP,EMME,GAM
            C         NUMERICAL CONSTANTS
0037                  G=32.174
0038                  CJ=778.16
0039                  EXP1=GAM/(GAM-1.)
0040                  EXP2=1./EXP1
0041                  ERRE=1545.43/EMME
0042                   BESP=(1.+( GAM-1.)/2.*0.64)**(-GAM/(GAM-1.))
0043                  READ(5,2)TIPC,ZS,ZR
0044                  READ (5,783) CV,CK
0045                  READ (5,2) (BETAO(I),I=1,5,2)
0046                  DO 611 I=1,5,2
0047             611      BETAO(I)= BETAO(I)*3.14159/180.
0048                  READ(5,784)(STALI(I),I=1,10)
0049                  READ(5,3)(A1(I),I=1,5)
0050                  READ(5,3)(A1(I),I=6,10)
0051                  READ(5,3)(A2(I),I=1,5)
0052                  READ(5,3)(A2(I),I=6,10)
0053                  READ(5,3301) AL,ALI,ALO
0054                  READ(5,3301)C,CI,CO
0055                  READ(5,3301)E,EI,EO
0056                  READ(5,3301)T,TI,TO
0057                  READ(5,3301)TE,TEI,TEO
0058                  READ(5,3301) TN,TNI,TNO
0059                  READ(5,3301)ALR,ALIR,ALOR
0060                  READ(5,3301) CR,CIR,COR
0061                  READ(5,3301) ER,EIR,EOR
0062                  READ(5,3301)TR,TIR,TOR
0063                  READ(5,3301) TER,TEIR,TEOR
0064                  READ(5,3301) TNR,TNIR,TNOR
            C
0065                  READ(5,1) RC(1),RC(5)
0066                  READ(5,1) RS(1),RS(5)
0067                  READ(5,1) RR(1),RR(5)
0068                  READ(5,3)TOL1,TOL2,TOL3,TOL4
0069            3341  FORMAT( 4E15.5)
0070                  RC(2)=SQRT(RC(5)*RC(5)/4.+3./4.*RC(1)*RC(1))
0071                  RC(3)=SQRT(RC(5)*RC(5)/2.+RC(1)*RC(1)/2.)
0072                  RC(4)=SQRT(3./4.*RC(5)*RC(5)+RC(1)*RC(1)/4.)
0073                  RS(2)=SQRT(RS(5)*RS(5)/4.    +RS(1)*RS(1)/4.*3.)
0074                  RS(3)=(RS(1) +RS(5) )/2.
0075                  RS(4)=SQRT(RS(5)*RS(5)/4.*3.+RS(1)*RS(1)/4.)
0076                  RR(2)=SQRT(RR(5)*RR(5)/4.+3./4.*RR(1)*RR(1))
0077                  RR(3)=(RR(1) +RR(5) )/2.
0078                  RR(4)=SQRT(RR(5)*RR(5)*3./4.+    RR(1)*RR(1)/4.)
0079                  DO 3300 I=1,10
0080                  A =I
0081                  R1(I)=RS(1)+(A-1.)/9. *(RS(5)-RS(1))
0082            3300  R2(I)=RR(1)+(A-1.)/9.*(RR(5)-RR(1))
0083                      DI= A1(1)
0084                   DD= A1(10)
0085                  DIR= A2(1)
0086                  DDR= A2(10)
0087                   DO 3711 I=1,10
```

```
             IF(RS(3).LE.R1(I)) GOTO 3712
       3711   CONTINUE
       3712  CONTINUE
             I=I-1
              O = A1(I)+ (A1(I+1)-A1(I))*(RS(3)-R1(I))/(R1(I+1)-R1(I))
             OO 3713 I=1,10
             IF(RR(3).LE.R2(I)) GOTO 3714
       3713   CONTINUE
       3714    CONTINUE
              I=I-1
              OR= A2(I)+ (A2(I+1)-A2(I))*(RR(3)-R2(I))/(R2(I+1)-R2(I))
            H=RS(5)-RS(1)
            O=2.*RS(3)
            S=2.*3.1416*RS(3)/ZS
            SI=2.*3.1415*RS(1)/ZS
            SO=2.*3.1416*RS(5)/ZS
            SZ=2.*3.1416*RR(3)/ZR
            SIR=2.*3.1416*RS(1)/ZR
            SOR=2.*3.1416*RS(5)/ZR
            DZ=2.*RR(3)
            HR=RR(5)-RR(1)
            ANG1=O.
      C
      C     AINLEY METHOD , STATOR EXIT ANGLES AT OIFFERENT  MACH NUMBERS
      C
              CL= TIPC
            CALL ANGAIN(ANG1,ALFAM(1),S,C,O,E,TE,0.5,O.,H,O,IWR,ANG21)
            CALL ANGAIN(ANG1,ALFAM(2),S,C,O,E,TE,0.7,O.,H,D,IWR,ANG21)
            CALL ANGAIN(ANG1,ALFAM(3),S,C,O,E,TE,0.75,O.,H,O,IWR,ANG21)
            CALL ANGAIN(ANG1,ALFAM(4),S,C,O,E,TE,0.80,O.,H,O,IWR,ANG21)
            CALL ANGAIN(ANG1,ALFAM(5),S,C,O,E,TE,1.0, O.,H,O,IWR,ANG21)
            ALFAX=ALFAM(1)
            OO 3303 I=1,5
       3303 ALFAM(I)=-ALFAM(I)
            O1I=2.*RC(1)
            O1O=2.*RC(5)
            O2I=2.*RS(1)
            O2O=2.*RS(5)
            CALL ANGAIN(ANG1,ANG2I,SI,CI,OI,EI,TEI,0.5,O.,H,D,IWR,ANG21)
            CALL ANGAIN(ANG1,ANG2O,SO,CO,OO,EO,TEO,0.5,O.,H,O,IWR,ANG21)
            DALF(1)=-ANG2I-ALFAM(1)
            OALF(3)=O.
            DALF(5)=-ANG2O-ALFAM(1)
      C
      C     ROTOR EXIT ANGLES
      C
            O1IR=2.*RR(1)
            O1OR=2.*RR(5)
            ANG1= BETAO(3)
            CALL ANGAIN(ANG1,BETAM(1),SZ,CR,OR,ER,TER,0.5,CL,HR,OZ,IWR,ANM)
            CALL ANGAIN(ANG1,BETAM(2),SZ,CR,OR,ER,TER,0.7,CL,HR,OZ,IWR,ANG21)
            CALL ANGAIN(ANG1,BETAM(3),SZ,CR,OR,ER,TER,0.75,CL,HR,OZ,IWR,ANG21)
            CALL ANGAIN(ANG1,BETAM(4),SZ,CR,OR,ER,TER,0.80,CL,HR,OZ,IWR,ANG21)
            CALL ANGAIN(ANG1,BETAM(5),SZ,CR,OR,ER,TER,1.00,CL,HR,OZ,IWR,ANG21)
              ANG1= BETAO(1)
            CALL ANGAIN(ANG1,BETAI,SIR,CIR,OIR,EIR,TEIR,0.5,O.,HR,OZ,IWR,AN)
              ANG1= BETAO(5)
            CALL ANGAIN(ANG1,BETAZ,SOR,COR,OOR,EOR,TEOR,0.5,O.,HR,OZ,IWR,AN)
            OBET(1)=BETAI-BETAM(1)
            OBET(3)=O.
            CL=TIPC
             ANG1= BETAO(5)
            CALL ANGAIN(ANG1,BETAC,SOR,COR,OOR,EOR,TEOR,0.5,CL,HR,OZ,IWR,AN)
              ANG1=O.
            DBET(5)=BETAC-BETAM(1)
            IF(IAN.EQ.1) GOTO 3377
      C
      C     ANGLES COMPUTATION  WITH TRAUPEL METHOO
      C
            OO 3370 I =1,5
       3370 ALFAM(I)=+ANGTRA(TN,S,O)
            ANG2I=+ANGTRA(TNI,SI,OI)
            ANG2O=+ANGTRA(TNO,SO,OO)
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```
0152            DALF(1)=      -ALFAM(1)+ANG2I
0153            DALF(3)=0.
0154            DALF(5)=      -ALFAM(1)+ANG2O
0155            DO 3371 I=1,5
0156      3371   BETAM(I)=- ANGTRA(TNR, SZ, OR)
0157            BETAI = -ANGTRA(TNIR,SIR,OIR)
0158            DBET(1)=-BETAM(1)+BETAI
0159            DBET(3)=0.
0160            BETAZ = -ANGTRA(TNOR,SOR,OOR)
0161            DBET(5)=-BETAM(1)+BETAZ
0162      3377  CONTINUE
0163            CALL PARAB (ALFAM,1,2,3,AA1,BA1,CA1,0.5,0.7,0.75)
0164            CALL PARAB(ALFAM,3,4,5,AA2,BA2,CA2,0.75,0.8,1.0)
0165            CALL PARAB (BETAM,1,2,3,AB1,BB1,CB1,0.5,0.7,0.75)
0166            CALL PARAB (BETAM,3,4,5,AB2,BB2,CB2,0.75,0.8,1.0)
0167            DO 10 I=1,5
0168            X1(I)=RS(I)/RS(3)
0169        10  X2(I)=RR(I)/RR(3)
0170            RROLD2=RR(2)
0171            RROLD3=RR(3)
0172            RROLD4=RR(4)
0173            RSOLD2=RS(2)
0174            RSOLD3=RS(3)
0175            RSOLD4=RS(4)
0176            RS1=RS(1)
0177            RS3=RS(3)
0178            RS5=RS(5)
0179            RR1=RR(1)
0180            RR3=RR(3)
0181            RR5=RR(5)
0182            CALL CHBFT(R1,A1,10,B1,4,T10,ST1,IRR)
0183            CALL CHBFT(R2,A2,10,B2,4,T10,ST1,IRR)
0184            ASF=B1(1)+B1(2)*RS(3)+B1(3)*RS(3)**2+B1(4)*RS(3)**3+B1(5)*RS(3)**4
0185            ARF=B2(1)+B2(2)*RR(3)+B2(3)*RR(3)**2+B2(4)*RR(3)**3+B2(5)*RR(3)**4
0186            RSF=RS(3)
0187            ASFO=ASF
0188            RSFO=RSF
0189            RRF=RR(3)
0190            RRFO=RRF
0191            ARFO=ARF
0192            XS1=X1(1)
0193            XS3=X1(3)
0194            XS5=X1(5)
0195            XR1=X2(1)
0196            XR3=X2(3)
0197            XR5=X2(5)
0198            DO 3410 I=1,5,2
0199      3410  BETAO(I)=BETAO(I)*180./3.14159
0200            CALL PARAB(BETAO,1,3,5,BR1,BR2,BR3,XS1,XS3,XS5)
0201            CALL CHBFT(R1,STALI,10,B6,4,T10,ST1,IRR)
          C
          C     INPUT  PRINTS
          C
0202            WRITE(6,671)
0203       671  FORMAT(1H1,//60X,12HIMPUT PRINTS//40X,50H       R1         A1
               1          R2          A2  /)
0204            DO 72 I=1,10
0205            WRITE(6,73)R1(I),A1(I),R2(I),A2(I)
0206        73  FORMAT(40X,F10.3,F10.4,10X,F10.3,F10.4)
0207        72  CONTINUE
0208            WRITE(6,74)ZS,ZR,TIPC,CV,CK
0209        74  FORMAT(/45X,25HNUMBER OF STATOR BLADES =,F8.0/45X,25HNUMBER OF ROT
               1OR  BLADES =,F8.0/45X,25HROTOR TIP CLEARANCE     =,F8.4/45X,25HAXI
               2AL DISTANCE L          =,F8.2/45X,25HCURVATURE FACTOR K      =,F8.2/
               3//55X,16HBLADING GEOMETRY/)
0210            WRITE(6,75)
0211        75  FORMAT(//30X,70H       C        E         T        TE          TN
               1      AL             R  /)
0212            WRITE(6,76)CI,EI,TI,TEI,TNI,ALI,RS(1),C,E,T,TE,TN,AL,RS(3),CO,EO,
               1TC,TEO,TNO,ALO,RS(5)
0213        76  FORMAT(30X,7F10.4/22X,6HSTATOR,2X,7F10.4/30X,7F10.4/)
0214      77    FORMAT(30X,7F10.4/22X,6HROTOR ,2X,7F10.4/30X,7F10.4/)
0215            WRITE(6,77)CIR,EIR,TIR,TEIR,TNIR,ALIR,RR(1),CR,ER,TR,TER,TNR,ALR,
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                   1RR(3),COR,EOR,TOR,TEOR,TNOR,ALOR,RR(5)
0216                WRITE(6,78)
0217             78 FORMAT(/40X,52HALL OIMENSIONS INOICATEO IN THIS TA8LE ARE IN INCHE
                   1S/)
0218                WRITE(6,79)ICOR,IAI,IAN,ICOZ,IINC,ICL,ICON
0219             79 FORMAT(////,40X,27HCORRELATION SYSTEM    ICOR =,I5/61X,6HIAI  =,I5/
                   161X,6HIAN  =,I5/61X,6HICOZ =,I5/,61X,6HIINC =,I5/61X,6HICL  =,I5/6
                   21X,6HICON =,I5)
0220                WRITE(6,81)CP,EMME,GAM,VIS2,VIS3
0221             81 FORMAT(/20X, 91HGAS PROPERTIES          CP        MOLECULAR MASS
                   1 GAMMA      VISCOSITY (1)     VISCOSITY (2)/38X,10H(8TU/L8 F),32X,13
                   2H(LBM /SEC FT),4X,13H(L8M /SEC FT)//36X,F9.3,5X,F10.3,9X,F7.3,2E15
                   3.3/)
0222              4 FORMAT(8I5)
0223                REAO (5,4) NSETS
0224           3404 FORMAT(10F8.3)
0225                OO 400 J=1,NSETS
0226                REAO (5,5) AMC,AMS,PTO,TTO,AMR,RPM,PR,VA1(3),VA2(3)
0227              5 FORMAT (9F8.4)
0228                OO 67 I=1,5
0229                U(I)=RPM*3.14159/30./12.*RS(I)
0230                OR(I)=0.
0231                OELR(I)=0.
0232                ZETAS(I)=.10
0233                ZETAR(I)=.15
0234                ZETAPS(I)=0.05
0235                ZETAPR(I)=0.05
0236                COSL(I)=1.
0237                YS(I)=1.0
0238             67 YR(I)=1.0
0239                N9=0
0240            750 NS=0
0241                N9=N9+1
0242           7750     CONTINUE
0243                IF( N9.GT.10.ANO. INZ.GE.1) GO TO 400
0244            290 IF(AMS-0.75) 30,40,50
0245             30 ALFA1(3)=AA1+BA1*AMS+CA1*AMS**2
0246                GO TO 60
0247             40 ALFA1(3)=ALFAM(3)
0248                GO TO 60
0249             50 IF (AMS-1.) 280,270,270
0250            270 ALFA1(3)=ALFAM(5)
0251                GO TO 60
0252            280 ALFA1(3)=AA2+8A2*AMS+CA2*AMS**2
0253             60 IF(AMR-0.75) 70,80,90
0254             70 8ETA2(3)=A81+B81*AMR+C81*AMR**2
0255                GO TO 100
0256             80 8ETA2(3)=8ETAM(3)
0257                GO TO 100
0258             90 8ETA2(3)=A82+882*AMR+CB2*AMR**2
0259            100 RS(2)=RSOL02
0260                RS(3)=RSOL03
0261                RS(4)=RSOL04
0262                OO 530 I=1,5
0263            530 X1(I)=RS(I)/RS(3)
0264                ASF=ASFO
0265                RSF=RSFO
0266                FS1=1.0
0267                FS2=1.0
0268                CALL CHAN (TTO,AMC,PTO,RC,WLBM,WCHAN,WPERO)
0269                NS=0
0270            810 OO 801 K=1,15
0271                CALL STATOR(ALFA1,X1,TTO,PTO,AMS,T1,P1,V1,VA1,SI1,SI2,YS,S1,
                   1OSOX1,VU1,PRAT1,T1IS,SS,OALF,AA1,BA1,CA1,AA2,BA2,CA2,ALFAM,RSF,
                   2OELR,CV,CK,ZETAPS,RS,RS1,RS3,RS5,ZETAS,OR,ZETA1, AMS1,NS,VR1)
0272                CALL ALOS1(ZETAS,ZETAPS)
0273                OO 120 I=1,5
0274                PTE(I)=PTO
0275            120 TTE(I)=TTO
0276                CALL FLOWR(PRAT1,ZETAPS,X1,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ASF,
                   1ZR,RSF,1,WCHAN,VA1,WPER1,COOE,WLBM,81,RS,TIPC,AREA1)
0277                 IF(IN.EQ.1) AMC= AMC-0.0001
0278                 IF(IN.EQ.1) GOTO 7750
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 D279            IF (CODE-20.)8D1,802,8D1
 0280        801 CONTINUE
 0281        802 CALL SLINE (RS,X1,DWOX,WPER1,WPERO,HE,U ,DHEOX,S1,OSDX1,ASF,RSF,
                1FS1,FS2,COOE,1,B1)
 0282            IF (COOE-40.)81C,3D0,810
 0283        300      CONTINUE
 0284            FC1=1.
 0285            FC2=FC1**2
 0286            ARF=ARFO
 0287            RRF=RROL03
 0288            RR(2)=RROL02
 0289            RR(3)=RRF
 0290            RR(4)=RROL04
 0291            OO 71 I=1,5
 0292            AMS1(I)=V1(I)/(SQRT(GAM*ERRE*G*T1(I)))
 0293            X2(I)=RR(I)/RR(3)
 0294         71 CONTINUE
 0295           OCALL ROTOR1(VU1,VA1,RPM,U,BETA1,HE,TTE,PTE,X2,P1,T1,W1,WU1,X1,
                1RS,ZETAR,ZETAPR,RR,OHEDX,DSDX1,S1,U2,OMEG,8R1,8R2,BR3,FS1,FS2,
                2 ZETAR   ,86,RS1,RS3,RS5,BETO,STALII,RINCI,VR1)
 0296            CDDE=1.
 0297             IMACC=0
 0298        201      DO 200 K=1,14
 D299            CALL ROTOR2 (BETA2,HE,OHEDX,OSDX1,OSOX2,VA2,WU2,W2,VU2,V2,X2,U2,
                1YR,ZETAR,RI1,RI2,RI3,RI4,RI,SR1,SR2,AA,SR,TTE,PTE,T2,P2,PRAT2,
                2T2S,INOS,OBET,BETAM,A81,B81,C81,A82,882,CB2,RRF,OELR,CV,CK,OR,RR,
                3RR1,RR3,RR5,NS,WR2)
 D30D            CALL ALOS2(ZETAR,ZETAPR)
 0301            IF (INOS-1) 310,320,310
 0302        320 WRITE (6,36) (AA(I),I=1,5)
 D303            WRITE(6,36)((AA(I),ZETAR(I),VA2(I)),I=1,5)
 0304         36 FDRMAT(35H ENTRCPY INOETERMINATE,PRINT AA 1-5,5E12.4/,25X,10HZETAR
                1 1-5,5E12.4/25X,10H VA2    1-5,5E12.4/)
 0305            IND=1
 0306            GD TO 400
 D307        310 CALL FLOWR(PRAT2,ZETAPR,X2,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ARF,ZR,
                1RRF,2,WCHAN,VA2,WPER2,CODE,WL8M,82,RR,TIPC,AREA2)
 03D8             IF(IN.EQ.1) AMC= AMC-0.0001
 0309             IF(IN.EQ.1) GOTO 7750
 0310            IF (CODE-2D.) 2D0,130,200
 0311        200 CCNTINUE
 0312        130 CALL SLINE (RR,X2,DWOX,WPER2,WPERO,HE,U ,OHEOX,S1,DSOX1,
                1ARF,RRF,FC1,FC2,CODE,2,B2)
 0313             IMACC= IMACC+1
 0314             IF( IMACC. GE.10) WRITE(6,4322) YR, ZETAR
 0315             IF( IMACC. GE.10) GOTO 220
 0316       4322   FORMAT( /20H  LOOP IN SLINE ROT//5E10.3)
 0317            IF(COOE-40.) 201,220,201
 0318       5D00   CONTINUE
 0319        220 DO 221 I=1,5
 032D            DELR(I)=RS(I)-(RC(I)+RR(I))/2.
 0321            OR(I)=RC(I)-RR(I)
 0322        221 COSL(I)=SQRT(CV*CV/(OR(I)**2+CV*CV))
 0323            NS=1
 0324        880 DO 881 K=1,15
 0325            CALL ALOS1( ZETAS,ZETAPS)
 0326            CALL STATOR(ALFA1,X1,TTC,PTO,AMS,T1,P1,V1,VA1,SI1,SI2,YS,S1,
                1DSOX1,VU1,PRAT1,T1IS,SS,DALF,AA1,BA1,CA1,AA2,8A2,CA2,ALFAM,RSF,
                2OELR,CV,CK,ZETAPS,RS,RS1,RS3,RS5,ZETAS,OR,ZETA1, AMS1,NS,VR1)
 0327            OO 86D I=1,5
 0328            PTE(I)=PTO
 0329        860 TTE(I)=TTO
 0330            CALL FLOWR(PRAT1,ZETAPS,X1,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ASF,
                1ZR,RSF,1,WCHAN,VA1,WPER1,COOE,WL8M,81,RS,TIPC,AREA1)
 0331             IF(IN.EQ.1) AMC= AMC-0.D001
 0332             IF(IN.EQ.1) GOTO 7750
 0333            IF (CODE-2D.)881,822,881
 0334        881 CONTINUE
 0335        822 CALL SLINE (RS,X1,DWDX,WPER1,WPERO,HE,U2,OHEDX,S1,OSOX1,ASF,RSF,
                1FS1,FS2,COOE,1,B1)
 0336            IF (CODE-40.) 8ED,861 ,880
 0337        861 CALL ROTOR1(VU1,VA1,RPM,U,8ETA1,HE,TTE,PTE,X2,P1,T1,W1,WU1,X1,
                1RS,ZETAR,ZETAPR,RR,DHEOX,DSDX1,S1,U2,OMEG,BR1,8R2,8R3,FS1,FS2,
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B94 DO B96 K=1,10
    CALL ALOS2( ZETAR,ZETAPR)
    CALL RDTDR2 (BETA2,HE,DHEDX,DSDX1,DSDX2,VA2,WU2,W2,VU2,V2,X2,U2,
   1YR,ZETAR,RI1,RI2,RI3,RI4,RI,SR1,SR2,AA,SR,TTE,PTE,T2,P2,PRAT2,
   2T2S,INDS,DBET,BETAM,AB1,BB1,CB1,AB2,BB2,CB2,RRF,DELR,CV,CK,DR,RR,
   3RR1,RR3,RR5,NS,WR2)
    IF(INDS-1)B95,320,B95
B95 CALL FLOWR(PRAT2,ZETAPR,X2,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ARF,ZR,
   1RRF,2,WCHAN,VA2,WPER2,CODE,WLBM,B2,RR,TIPC,AREA2)
     IF(IN.EQ.1) AMC= AMC-0.0001
     IF(IN.EQ.1) GOTO 7750
    IF(CODE-20.)B96,B97,B96
896 CONTINUE
B97 CALL SLINE (RR,X2,DWDX,WPER2,WPERD,HE,U2,DHEDX,S1,DSDX1,
   1ARF,RRF,FC1,FC2,CODE,2,B2)
    IF (CODE-40.)894,226,B94
226 DO 227 I=1,5
227 PRAT3(I)=PTO/P2(I)
    IND=0
    PRAT5=(PRAT3(1)+2.*(PRAT3(2)+PRAT3(3)+PRAT3(4))+PRAT3(5))/B.
    DIFF=ABS(PR-PRAT5)
    TAL=TOL3*PR
    IF(TAL  -DIFF)910,920,920
910 N11=0
      REC3= AMC
     DIFFE=PR-PRAT5
    IF(N9.GE.2) AMC=AMC+ DIFFE*(AMC-REC2)/ (REC1-DIFFE)*0.75
     REC2= REC3
      REC1= DIFFE
    IF(N9.LE.1)GOTO 710
    IF(INZ.EQ.1) GOTO 223
    IF(N9.GT.9) GOTC 223
    GOTO 750
920 N11=1
    GO TO 223
710 IF(PR-PRAT5)712,712,714
712 AMC= AMC*( 1.- CIFF/PR*0.100)
    IF(INZ-1)750,223,223
714 AMC= AMC*( 1.+ DIFF/PR*0.100)
    IF(INZ-1)750,223,223
223 CONTINUE
999 FORMAT (1H1)
    WRITE(6,999)
    WRITE(6,401)
401 FORMAT(///27X,67HSET      PAGE      RPM    TOTAL/STATIC      INLET T
   1OTAL   INLET TOTAL)
    WRITE(6,402)
402 FORMAT(   27X,67HNUMBER  NUMBER             PRESSURE RATIO   PRESSUR
   1E       TEMPERATURE)
    WRITE(6,403)
403 FORMAT(72X, 5H(PSI), 7X,BH(DEG. R)/)
    IS=1
    WRITE(6,405)J,IS,RPM,PR,PTO,TTO
405 FORMAT(27X,I3,IB,F11.1,F14.3,F14.3,F15.2/)
    WRITE(6,404)
404 FORMAT(//57X21H STATOR EXIT SOLUTION///)
    WRITE(6,406)
406 FORMAT(1X,109HSTREAM    RADIAL    X=R/RM   RADIAL   BLADE     Y=VA
   1/VAM     BLADE          LOSS          ZETA*        FLOW RATE)
    WRITE(6,407)
407 FORMAT(1X,109H LINE    POSITION                SHIFT   OPENING
   1        EFFICIENCY   COEFFICIENT   CONTINUITY    FRACTION /)
    WRITE(6,411)
411 FORMAT(12X,4H(IN),13X,4H(IN),5X,4H(IN))
    DO 408 I=1,5
    PRAT1(I)=1./PRAT1(I)
    RINCI(I)=RINCI(I)*57.3
    ALFA11(I)=ALFA1(I)*57.3
    BETA11(I)=BETA1(I)*57.3
    ALFA2(I)=ATAN(VU2(I)/VA2(I))
    V2(I)=VA2(I)/COS(ALFA2(I))
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0401            V2(I)=SQRT(V2(I)*V2(I)+WR2(I)*WR2(I))
0402            ALFA22(I)=ALFA2(I)*57.3
0403            BETA22(I)=BETA2(I)*57.3
0404            OELH(I)=(U(I)*VU1(I)-U2(I)*VU2(I))/(G*CJ)
0405            TT2(I)=TTO-OELH(I)/CP
0406            PT2(I)=P2(I)*(TT2(I)/T2(I))**EXP1
0407            PT1(I)=P1(I)*(TTO/T1(I))**EXP1
0408            T2IS(I)=TTO*(P2(I)/PTO)**EXP2
0409            T2S(I)=TTE(I)*(P2(I)/PTE(I))**EXP2
0410             TTIS(I)= TTO*(PT2(I)/PTO)**EXP2
0411            BETAT(I)= PTO/PT2(I)
0412            ETAT(I)= (TTO-TT2(I))/(TTO-TTIS(I))
0413            ETAI(I)=(TTO-TT2(I))/(TTO-T2IS(I))
0414            ETAS(I)=(TTO-T1(I))/(TTO-T1IS(I))
0415            ETAR(I)=(TTE(I)-T2(I))/(TTE(I)-T2S(I))
0416            RSTAR(I)=(T1IS(I)-T2IS(I))/(TTO-T2IS(I))
0417            AKIS(I)=2.*G*CJ*CP*(TTO-T2IS(I))/U(I)**2
0418            PSIR(I)=SQRT(ETAR(I))
0419            OR1(I)=RC(I)-RS(I)
0420            AMW1(I)=W1(I)/SQRT(GAM*ERRE*G*T1(I))
0421            AMS1(I)=V1(I)/SQRT(GAM*ERRE*G*T1(I))
0422            AMV2(I)=V2(I)/SQRT(GAM*ERRE*G*T2(I))
0423            AMR2(I)=W2(I)/SQRT(GAM*ERRE*G*T2(I))
0424            8ETET(I)=PTE(I)/P2(I)
0425            PRAT1T(I)=PTO/PT1(I)
0426        408 WRITE(6,409) I,RS(I),X1(I),OR1(I),AREA1(I),YS(I),ETAS(I),ZETA1(I),
               1ZETAPS(I),WPER1(I)
0427            OELH(10)=0.
0428            OO 240 I=1,4
0429            L=I+1
0430        240 OELH(10)=OELH(10)+.5*(WPER2(L)-WPER2(I))*(DELH(L)+OELH(I))
0431            HP=OELH(10)*CJ*WL8M/550.
0432            AMOM=HP*550./OMEG
0433            THETA=SQRT(TTO/518.4)
0434            OELTA=PTO/14.7
0435            HP1=HP/(THETA*OELTA)
0436            AMOM1=AMOM/OELTA
0437            RPM1=RPM/THETA
0438            WL8M1=WL8M*THETA/OELTA
0439            ETA5=(ETAI(1)+ETAI(5)+2.*(ETAI(2)+ETAI(3)+ETAI(4)))/8.
0440             8ETA6=(8ETAT(1)+8ETAT(5) + 2.*(BETAT(2)+BETAT(3) +8ETAT(4)))/8.
0441              ETA6=( ETAT(1)+ ETAT(5) + 2.*( ETAT(2)+ ETAT(3) + ETAT(4)))/8.
0442            AKIS5=(AKIS(1)+AKIS(5)+2.*(AKIS(2)+AKIS(3)+AKIS(4)))/8.
0443            RSTAR5=(RSTAR(1)+RSTAR(5)+2.*(RSTAR(2)+RSTAR(3)+RSTAR(4)))/8.
0444        409 FORMAT(1X,I4,F12.3,F10.3,F9.4,F9.4,F11.4,F11.4,F14.4,F13.4,F14.4)
0445            WRITE(6,412)
0446        412 FORMAT(///22X,23HABSOLUTE VELOCITY (FPS),27X,23HRELATIVE VELOCITY
               1(FPS)//)
0447        413 FORMAT(1X,6HSTREAM,2X,2(50H  AXIAL       RAOIAL   TANGENTIAL   OVER
               1ALL          ),7H WHEEL )
0448            WRITE(6,413)
0449            WRITE(6,414)
0450        414 FORMAT(1X,6H LINE ,   2(50HCOMPONENT   COMPONENT   COMPONENT    VE
               1LOCITY       ),8HVELOCITY//)
0451            OO 415 I=1,5
0452        415 WRITE(6,416) I,VA1(I),VR1(I),VU1(I),V1(I),VA1(I),VR1(I),WU1(I),W1(
               1I),U(I)
0453        416 FORMAT(I5,2X,2(F8.2,3F12.2,6X),F8.2)
0454            WRITE(6,418)
0455        418 FORMAT(///7X,113H       MACH NUMBER               FLOW ANGLE
               1      TEMPERATURE               PRESSURE                 PRESSURE)
0456            WRITE(6,419)
0457        419 FORMAT(    7X,113H                                  (OEG)
               1         (DEG. R)              (PSI)                    RATIO  /)
0458            WRITE(6,492)
0459        492 FORMAT(  7H STREAM)
0460            WRITE(6,420)
0461        420 FORMAT(7H  LINE ,2(24H   ABSOLUTE  RELATIVE   ),2(24H     TOTAL
               1 STATIC     ),24H    TOT/TOT    TOT/STA   /)
0462            OO 422 I=1,5
0463        422 WRITE(6,421)I,AMS1(I),AMW1(I),ALFA11(I),BETA11(I),TTO,T1(I),PT1(I)
               1,P1(I),PRAT1T(I),PRAT1(I)
0464        421 FORMAT(I4,3X,2F10.2,4X,2F10.2,4X,2F10.2,4X,2F1C.3,4X,F11.4,F10.4)
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          WRITE(6,999)
          WRITE(6,401)
          WRITE(6,402)
          WRITE(6,403)
      452 FORMAT(//57X,21H  ROTOR EXIT SOLUTION///)
          IS=2
          WRITE(6,405) J,IS,RPM,PR,PTO,TTO
          WRITE(6,452)
          WRITE(6,406)
          WRITE(6,407)
          OO 423 I=1,5
      423 WRITE(6,409)I,RR(I),X2(I),OR(I),AREA2(I),YR(I),ETAR(I),ZETAR(I),
         1ZETAPR(I),WPER2(I)
          WRITE(6,412)
          WRITE(6,413)
          WRITE(6,414)
          DO 424 I=1,5
      424 WRITE(6,416)I,VA2(I),WR2(I),VU2(I),V2(I),VA2(I),WR2(I),WU2(I),W2(I
         1),U2(I)
          WRITE(6,418)
          WRITE(6,419)
          WRITE(6,492)
          WRITE(6,420)
          OO 425 I=1,5
      425 WRITE(6,421) I,AMV2(I),AMR2(I),ALFA22(I),8ETA22(I),TT2(I),T2(I),
         1PT2(I),P2(I), BETAT(I),PRAT3 (I)
          WRITE(6,491)
      491 FORMAT(///)
          WRITE(6,426)
      426 FORMAT(7H STREAM, 74H   EQUIVALENT   EQUIVALENT   EQUIV/STATIC   8
         1LADE    BLAOE         INCIDENCE)
      427 FORMAT(7H LINE   , 74H   TEMPERATURE   INLET         PRESSURE      I
         1NLET    STALL          ANGLE  )
      428 FORMAT(  7X,         74H                  PRESSURE        RATIO      A
         1NGLE    ANGLE                  )
      429 FORMAT( 7X,          74H    (OEG. R)      (PSI)                      (
         1OEG)    (DEG)          (OEG)  /)
          WRITE(6,427)
          WRITE(6,428)
          WRITE(6,429)
          DO 430 I=1,5
      430 WRITE(6,431)I,TTE(I),PTE(I),BETET(I),BETO(I),STALII(I),RINCI(I)
      431 FORMAT(I4,F13.2,F13.2,F15.3,F11.1,F9.1,F14.1)
          WRITE(6,999)
          WRITE(6,401)
          WRITE(6,402)
          WRITE(6,403)
          IS=3
          WRITE(6,405)J,IS,RPM,PR,PTO,TTO
          WRITE(6,441)
     441  FORMAT(//45X,31HOVERALL TUR8INE CHARACTERISTICS///)
          WRITE(6,442)
      442 FORMAT(102H  STREAM       PRESSURE RATIO            EFFICIENCY
         1    HEAO          8LAOE/JET       THEORETICAL      )
          WRITE(6,443)
      443 FORMAT(102H   LINE     TOT/STA    TOT/TOT    TOT/STA       TOT/TOT
         1   COEFFICIENT   SPEEO RATIO OEGREE OF REACTION /)
          DO 444 I=1,5
          8LAJE=1./SQRT(AKIS(I))
     444  WRITE(6,445) I,PRAT3(I),8ETAT(I),ETAI(I),ETAT(I),AKIS(I),8LAJE,RST
         1AR(I)
      445 FORMAT(I5,F14.4,F11.4,F11.4,F13.4,F12.4,F15.4,F16.4)
          WRITE(6,446)
     446  FORMAT(///53X,24HMASS AVERAGEO QUANTITIES///)
     447  FORMAT(52X,13HHCRSE POWER =,F10.2,3X,4H(HP))
     448  FORMAT(52X,13HMOMENT      =,F10.2,3X,7H(FT-LB))
     449  FORMAT(52X,13HFLOW RATE   =,F10.2,3X,8H(LB/SEC)//)
     461  FORMAT(43X,22HREFERREO  RPM          =,F10.2)
     462  FORMAT(43X,22HREFERREO HORSE POWER =,F10.2,3X,4H(HP))
     463  FORMAT(43X,22HREFERREO MOMENT      =,F10.2,3X,7H(FT-L8))
     464  FORMAT(43X,22HREFERREO FLOW RATE   =,F10.2,3X,8H(L8/SEC)//)
      465 FORMAT(40X,25HTOTAL/STATIC EFFICIENCY =,F10.4)
     466  FORMAT(40X,25HTCTAL/TOTAL  EFFICIENCY =,F10.4//)
```

```
  467  FORMAT(36X,29HTOTAL/STATIC PRESSURE RATIO =,F10.4)
  468  FORMAT(36X,29HTOTAL/TOTAL  PRESSURE RATIO =, F10.4//)
  469  FORMAT(34X,31HHEAD COEFFICIENT              =,F10.4)
  471  FORMAT(34X,31HTHEORETICAL OEGREE OF REACTION=,F10.4)
  472  FORMAT(34X,31HBLAOE/JET SPEED RATIO         =,F10.4)
  473  FORMAT(34X,31HMACH NUM8ER AT STATION O      =,F10.4)
       WRITE(6,447)HP
       WRITE(6,448)AMCM
       WRITE(6,449)WLBM
       WRITE(6,461)RPM1
       WRITE(6,462)HP1
       WRITE(6,463)AMCM1
       WRITE(6,464)WL8M1
       WRITE(6,465)ETA5
       WRITE(6,466)ETA6
       WRITE(6,467)PRAT5
       WRITE(6,468)8ETA6
       WRITE(6,469)AKIS5
       8LAJE5=1./SQRT(AKIS5)
       WRITE(6,472)8LAJE5
       WRITE(6,471) RSTAR5
       WRITE(6,473) AMC
       IF(INZ-1)400,930,930
  930  IF(N11-1)750,400,400
  400  CONTINUE
       ENO
```

```
      SUBROUTINE CHAN (TTO,AMC,PTO,RC,WLBM,WCHAN,WPERO)
      COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
      CCMMON /CSS/ CJ,G,C1
      DIMENSION RC(10),WPERO(10)
      TC=TTO/(1.+(GAM-1.)/2.*AMC*AMC)
      VC=SQRT(GAM*ERRE*G*TC)*AMC
      PC=PTO/(1.+(GAM-1.)*AMC**2/2.)**EXP1
      RHO=PC/ERRE/TC
      AREA= 3.1416*(RC(5)**2-RC(1)**2)
      WLBM=RHO*AREA*VC
      WCHAN=WLBM/(PTO*SQRT(G/ERRE/TTO))
      WPERO(1)=0.
      WPERO(2)=.25
      WPERO(3)=.5
      WPERO(4)=.75
      WPERO(5)=1.
      RETURN
      END
```

```
0001               SUBROUTINE STATOR (ALFA1,X,TTO,PTO,AM,T,P,V1,VA1,SI1,SI2,Y,S,OSOX,
                  1VU1,PRAT,T1IS,SS,OALF,AA1,BA1,CA1,AA2,BA2,CA2,ALFAM,RSF,OELR,
                  2CL,CK,ZETAPS,R,RS1,RS3,RS5,ZETA,OR,ZETAS,AMS,NS,VR1)
0002               OOIMENSION ALFA1(10),X(10),T(10),P(10),V1(10),VA1(10),SI1(10),
                  1SI2(10),Y(10),S(10),OSOX(10),VU1(10),PRAT(10),T1IS(10),SS(10)
                  2,OALOX(10),ALFA(10),OALF(10),ALFAM(10),AMS(10),OALFOX(10),OELR(10)
                  3,ZETAS(10),ETA(10),ZETAPS(10),R(10),ZETA(10),OR(10),VR1(10)
0003               COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0004               COMMON /CSS/ CJ,G,C1
0005               COMMON /IWI/ IND,INZ,IWR
0006               C8=0.0
0007               C9=0.0
0008               C1=2.*CJ*G*CP
0009               C2=VA1(3)**2/(C1*TTO)
0010               OO 303 I=1,5
0011               IF(R(I)-RS3)300,301,302
0012           300 ZETAS(I)=ZETA(1)+(R(I)-RS1)/(RS3-RS1)*(ZETA(3)-ZETA(1))
0013               ALFA1(I)=ALFA1(3)+(R(I)-RS3)/(RS1-RS3)*OALF(1)
0014               ZETAPS(I)=ZETAPS(1)+(R(I)-RS1)/(RS3-RS1)*(ZETAPS(3)-ZETAPS(1))
0015               GO TO 303
0016           301 ZETAS(I)=ZETA(3)
0017               ALFA1(I)=ALFA1(3)
0018               GO TO 303
0019           302 ZETAS(I)=ZETA(3)+(R(I)-RS3)/(RS5-RS3)*(ZETA(5)-ZETA(3))
0020               ALFA1(I)=ALFA1(3)+(R(I)-RS3)/(RS5-RS3)*OALF(5)
0021               ZETAPS(I)=ZETAPS(3)+(R(I)-RS3)/(RS5-RS3)*(ZETAPS(5)-ZETAPS(3))
0022          303  CONTINUE
0023               OO 305 I=1,5
0024               ETA(I)=1.-ZETAS(I)
0025               M=I-1
0026               N=I+1
0027               IF (I-1)307,3C7,309
0028           307 OALFOX(1)=(ALFA1(2)-ALFA1(1))/(X(2)-X(1))
0029               GO TO 315
0030           309 IF(I-5)311,313,313
0031           311 CALFOX(I)=.5*((ALFA1(N)-ALFA1(I))/(X(N)-X(I))+(ALFA1(I)-ALFA1(M))/
                  1(X(I)-X(M)))
0032               GO TO 315
0033           313 OALFOX(5)=(ALFA1(5)-ALFA1(4))/(X(5)-X(4))
0034           315 TAN1=-2.*TAN(ALFA1(I))
0035               PROO=TAN1*OALFOX(I)
0036               SINSQ=-2.*SIN(ALFA1(I))**2/X(I)
0037               SI1(I)=PROO+SINSQ
0038           305 CONTINUE
0039           304 OO 332 J=1,5
0040               IF(J-1)306,306,310
0041           306 IF(NS-1)317,310,310
0042           317 OO 308 I=1,5
0043               SS(I)=0.
0044           308 SI2(I)=SI1(I)
0045               GO TO 318
0046           310 OO 312 I=1,5
0047               AA=C2*Y(I)**2/COS(ALFA1(I))**2
0048               AB=(1.-AA)/(1.-AA/ETA(I))
0049           312 S(I)=ALOG(AB)
0050           314 OSOX(1)=(S(2)-S(1))/(X(2)-X(1))
0051               OSOX(2)=0.5*(OSOX(1)+(S(3)-S(2))/(X(3)-X(2)))
0052               OSOX(3)=0.5*((S(4)-S(3))/(X(4)-X(3))+(S(3)-S(2))/(X(3)-X(2)))
0053               OSOX(4)=0.5*((S(5)-S(4))/(X(5)-X(4))+(S(4)-S(3))/(X(4)-X(3)))
0054               OSOX(5)=(S(5)-S(4))/(X(5)-X(4))
0055               OO 316 I=1,5
0056               IF(NS-1)319,321,321
0057           319 SS(I)=(1.-COS(ALFA1(I))**2/(C2*Y(I)**2))*OSOX(I)
0058               GO TO 316
0059           321 SS(I)=((-COS(ALFA1(I))**2/(C2*Y(I)**2))+SIN(ALFA1(I))**2+COS(AL
                  1FA1(I))**2*(CL**2+(OR(I)/2.0)**2)/CL**2)*OSOX(I)+COS(ALFA1(I))**2*
                  2CK*2.*RSF*OELR(I)/CL**2
0060           316 SI2(I)= SS(I)+SI1(I)
0061           318 SUM1=(SI2(1)+SI2(2))*(X(2)-X(1))/4.
0062               SUM2=(SI2(2)+SI2(3))*(X(3)-X(2))/4.
0063               SUM3=(SI2(3)+SI2(4))*(X(4)-X(3))/4.
0064               SUM4=(SI2(4)+SI2(5))*(X(5)-X(4))/4.
0065               EN2=-SUM2
```

```
          EN1=-SUM2-SUM1
          EN3=SUM3
          EN4=SUM3+SUM4
          Y(1)= EXP(EN1)
          Y(2)= EXP(EN2)
          Y(3)=1.
          Y(4)= EXP(EN3)
          Y(5)= EXP(EN4)
          IF(IND-1)332,323,323
      323 IF(J-1)324,324,320
      320 IF(J-3)322,324,322
      322 IF(J-5)332,324,332
      324 WRITE (6,326)
      326 FORMAT (/57H SLINE  C8  C9  ITERATION  I'ALFA  I'DSDX  I'TOTAL
         1  Y)
          DO 330 I=1,5
      328 FORMAT (I4,F4.2,F4.2,I9,F12.4,F9.5,F9.4,2F8.4)
      330 WRITE (6,328) I,C8,C9,J,SI1(I),SS(I),SI2(I),Y(I),ALFA1(I)
      332 CONTINUE
          DO 334 I=1,5
          VA1(I)=VA1(3)*Y(I)
          VU1(I)=VA1(I)*TAN(ALFA1(I))
          V1(I)=VA1(I)/COS(ALFA1(I))
          VR1(I)=-VA1(I)*DR(I)/2./CL
          V1(I)=SQRT(V1(I)*V1(I)+VR1(I)*VR1(I))
          T(I)=TTO-V1(I)**2/C1
          T1IS(I)=TTO-(TTO-T(I))/ETA(I)
          P(I)=PTO*(T1IS(I)/TTO)**EXP1
      334 PRAT(I)=P(I)/PTO
          C9=C9+1.
          IF(C9-2.)336,356,356
      336 DO 352 I=1,5
          AMS(I)=V1(I)/SQRT(GAM*ERRE*G*T (I))
          IF (AMS(I)-.75)338,344,346
      338 IF (AMS(I)-.5)340,340,342
      340 ALFA(3)=ALFAM(1)
          GO TO 348
      342 ALFA(3)=AA1+BA1*AMS(I)+CA1*AMS(I)**2
          GO TO 348
      344 ALFA(3)=ALFAM(3)
          GO TO 348
      346 ALFA(3)=AA2+BA2*AMS(I)+CA2*AMS(I)**2
      348 IF(R(I)-RS3)339,350,341
      339 ALFA1(I)=ALFA(3)+(R(I)-RS3)/(RS1-RS3)*DALF(1)
          GO TO 352
      350 ALFA1(I)=ALFA(3)
          GO TO 352
      341 ALFA1(I)=ALFA(3)+(R(I)-RS3)/(RS5-RS3)*DALF(5)
      352 CONTINUE
          DO 354 I=1,5
          M=I-1
          N=I+1
          IF (I-1)347,347,349
      347 DALFDX(1)=(ALFA1(2)-ALFA1(1))/(X(2)-X(1))
          GO TO 355
      349 IF(I-5)351,353,353
      351 DALFDX(I)=.5*((ALFA1(N)-ALFA1(I))/(X(N)-X(I))+(ALFA1(I)-ALFA1(M))/
         1(X(I)-X(M)))
          GO TO 355
      353 DALFDX(5)=(ALFA1(5)-ALFAI(4))/(X(5)-X(4))
      355 TAN1=-2.*TAN(ALFA1(I))
          PROD=TAN1*DALFDX(I)
          SINSQ=-2.*SIN(ALFA1(I))**2/X(I)
          SI1(I)=PROD+SINSQ
      354 CONTINUE
          GO TO 304
      356 RETURN
          END
```

```
0001          0SUBROUTINE RDTOR1(VU1,VA1,RPM,U,BETA1,HE,TTE,PTE,X2,P1,T1,W1,WU1,
              1X1,RS,ZETAR,ZETAPR,RR,DHEDX,DSDX,S,U2,OMEG,BR1,BR2,BR3,FS1,FS2,
              2ZETA     ,B6,RS1,RS3,RS5,BETO,STALI,BINC,VR1)
0002          0DIMENSION VU1(10),VA1(10),U(10),BETA1(10),HE(10),TTE(10),PTE(10),
              1X2(10),P1(10),T1(10),W1(10),WU1(10),X1(10),RS(10),ZETAR(10),
              2ZETAPR(10),RR(10),DHEDX(10),DSDX(10),S(10),U2(10),ZETA(10)
              3 ,VR1(10)          ,B6(20),BETO(10),STALI(10),BINC(10)
0003           COMMON /CSS/ CJ,G,C1
0004           COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0005           COMMON /IWI/ INC,INZ,IWR
0006           C=2.*32.174*778.16*CP
0007           OMEG=RPM*3.1416/30.
0008           DO 520 I=1,5
0009           U(I)=OMEG*RS(I)/12.
0010           U2(I)=U(I)*RR(I)/RS(I)
0011           WU1(I)=VU1(I)-U(I)
0012           BETA1(I)=ATAN(WU1(I)/VA1(I))
0013           W1(I)=VA1(I)/COS(BETA1(I))
0014           W1(I)=SQRT(VR1(I)*VR1(I)+W1(I)*W1(I))
0015           TTE(I)=T1(I)+W1(I)**2/C+(U2(I)**2-U(I)**2)/C
0016           PTE(I)=P1(I)*(TTE(I)/T1(I))**EXP1
0017           HE(I)=TTE(I)*.24
0018           BETO(I)=BR1+FS1*BR2*X1(I)+FS2*BR3*X1(I)**2
0019           STALI(I)=B6(1)+B6(2)*RS(I)+B6(3)*RS(I)**2+B6(4)*RS(I)**3+B6(5)*RS
              1(I)**4
0020           BINC(I)=BETA1(I)-BETO(I)/57.3
0021           IF(RS(I)-RS3)512,514,516
0022       512 ZETAR(I)=ZETA(1)+(RS(I)-RS1)/(RS3-RS1)*(ZETA(3)-ZETA(1))
0023           GO TO 518
0024       514 ZETAR(I)=ZETA(3)
0025           GO TO 518
0026       516 ZETAR(I)=ZETA(3)+(RS(I)-RS3)/(RS5-RS3)*(ZETA(5)-ZETA(3))
0027       518 ZETAPR(I)=ZETAR(I)/2.0
0028       520 CONTINUE
0029           DSDX(1)=(S(2)-S(1))/(X2(2)-X2(1))
0030           DSDX(2)=0.5*(DSDX(1)+(S(3)-S(2))/(X2(3)-X2(2)))
0031           DSDX(3)=0.5*((S(4)-S(3))/(X2(4)-X2(3))+(S(3)-S(2))/(X2(3)-X2(2)))
0032           DSDX(5)=(S(5)-S(4))/(X2(5)-X2(4))
0033           DSDX(4)=0.5*(DSDX(5)+(S(4)-S(3))/(X2(4)-X2(3)))
0034           DHEDX(1)=(HE(2)-HE(1))/(X2(2)-X2(1))
0035           DHEDX(2)=0.5*(DHEDX(1)+(HE(3)-HE(2))/(X2(3)-X2(2)))
0036          0DHEDX(3)=0.5*((HE(3)-HE(2))/(X2(3)-X2(2))+(HE(4)-HE(3))/
              1 (X2(4)-X2(3)))
0037           DHEDX(5)=(HE(5)-HE(4))/(X2(5)-X2(4))
0038           DHEDX(4)=0.5*(DHEDX(5)+(HE(4)-HE(3))/(X2(4)-X2(3)))
0039       522 CONTINUE
0040           RETURN
0041           END
```

```
0001          SUBROUTINE ROTOR2 (BETA2,HE,DHEDX,DSDX1,DSDX2,VA2,WU2,W2,VU2,V2,
             1X2,U,YR,ZETAR,RI1,RI2,RI3,RI4,RI,SR1,SR2,AA,SR,TTE,PTE,T2,P2,PRAT2
             2,T2S,INDS,DBET,BETAM,AB1,BB1,CB1,AB2,BB2,CB2,RRF,DELR,CL,CK,DR,R,
             3RR1,RR3,RR5,NS,WR2)
0002          DIMENSION BETA2(10),HE(10),DHEDX(10),DSDX1(10),DSDX2(10),VA2(10),
             1WU2(10),W2(10),VU2(10),V2(10),X2(10),U(10),YR(10),ZETAR(10),
             2RI1(10),RI2(10),RI3(10),RI4(10),RI(10),SR1(10),SR2(10),YOLD(10),
             3AA(10),SR(10),TTE(10),PTE(10),T2(10),P2(10),PRAT2(10),T2S(10),
             4DBET(10),BETAM(10),AMR(10),DBETDX(10),BETA(10),DELR(10),RI5(10)
             5,DR(10),R(10),WR2(10)
0003          COMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0004          COMMON /CSS/ CJ,G,C1
0005          COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0006          COMMON /IWI/ IND,IN2,IWR
0007          INDS=0
0008          INDS1=0
0009          C=2.*G*CJ
0010          C1=C/VA2(3)**2
0011          DO 274 I=1,5
0012          IF(R(I)-RR3)270,271,273
0013      270 BETA2(I)=BETA2(3)+(R(I)-RR3)/(RR1-RR3)*DBET(1)
0014          GO TO 274
0015      271 BETA2(I)=BETA2(3)
0016          GO TO 274
0017      273 BETA2(I)=BETA2(3)+(R(I)-RR3)/(RR5-RR3)*DBET(5)
0018      274 CONTINUE
0019          DBETDX(1)=(BETA2(2)-BETA2(1))/(X2(2)-X2(1))
0020          DBETDX(5)=(BETA2(5)-BETA2(4))/(X2(5)-X2(4))
0021          DO 280 I=2,4
0022          M=I-1
0023          N=I+1
0024      280 DBETDX(I)=.5*((BETA2(N)-BETA2(I))/(X2(N)-X2(I))+(BETA2(I)-BETA2
             1(M))/(X2(I)-X2(M)))
0025          DO 10 I=1,5
0026      200 TAN1=-2.*TAN(BETA2(I))
0027          PROD=TAN1*DBETDX(I)
0028          SIN1=-2.*SIN(BETA2(I))**2/X2(I)
0029          RI1(I)=PROD+SIN1+DSDX1(I)
0030          SR1(I)=-4.*U(3)*COS(BETA2(I))*SIN(BETA2(I))/(VA2(3)*YR(I))
0031          SR2(I)=2.*U(3)*U(I)*COS(BETA2(I))**2/(VA2(3)**2*YR(I)**2)
0032          YCLO(I)=YR(I)
0033          AA(I)=(VA2(3)*YR(I)/COS(BETA2(I)))**2/(C*HE(I))
0034          RI3(I)=C*COS(BETA2(I))**2/(VA2(3)*YR(I))**2*DHEDX(I)
0035          IF (INDS1-1)10,250,250
0036       10 CONTINUE
0037      281 IF(IND-1)201,282,282
0038      282 WRITE (6,121)(RI1(I),I=1,5)
0039      121 FORMAT(/23H CONSTANT INTEGRAND 1-5, 5F8.5)
0040          WRITE (6,122)
0041      122 FORMAT(/60H SLINE   INDS1   GRAD S    INT2    INT3     INT4     INT
             1Y VAL)
0042      201 DO 20 J=1,13
0043          DO 30 I=1,5
0044          AA(I)=AA(I)*(YR(I)/YOLD(I))**2
0045          ANUM=1.-AA(I)
0046          ADEN=1.-AA(I)/(1.-ZETAR(I))
0047          AB=ANUM/ADEN
0048          IF (AB) 130,130,30
0049      130 INDS=1
0050          GO TO 150
0051       30 SR(I)=ALOG(ANUM/ADEN)
0052          DSDX2(1)=(SR(2)-SR(1))/(X2(2)-X2(1))
0053          DSDX2(2)=0.5*(DSDX2(1)+(SR(3)-SR(2))/(X2(3)-X2(2)))
0054          DSDX2(3)=0.5*((SR(3)-SR(2))/(X2(3)-X2(2))+(SR(4)-SR(3))/
             1 (X2(4)-X2(3)))
0055          DSDX2(5)=(SR(5)-SR(4))/(X2(5)-X2(4))
0056          DSDX2(4)=0.5*(DSDX2(5)+(SR(4)-SR(3))/(X2(4)-X2(3)))
0057          DO 40 I=1,5
0058          SR1(I)=SR1(I)*YCLO(I)/YR(I)
0059          SR2(I)=SR2(I)*(YOLD(I)/YR(I))**2
0060          RI2(I)=SR1(I)-SR2(I)
0061          RI3(I)=RI3(I)*(YOLD(I)/YR(I))**2
0062          IF(NS-1)31,32,32
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```
0063          31 RI4(I)=DSOX2(I)-(DSDX1(I)+OSDX2(I))*C1*HE(I)
               1 *(CDS(BETA2(I))/YR(I))**2
0064             GO TO 40
0065          32 RI4(I)=-(OSOX1(I)+DSOX2(I))*C1*HE(I)*(COS(BETA2(I))/YR(I))**2
0066             RI5(I)=(DSDX1(I)+OSDX2(I))*(SIN(BETA2(I))**2+COS(BETA2(I))**2
                1*((CL**2+(OR(I)/2.0)**2)/CL**2))-COS(BETA2(I))**2*(2.*CK*RRF*
                2OELR(I))/CL**2
0067             RI4(I)=RI4(I)+RI5(I)
0068          40 RI(I)=RI1(I)+RI2(I)+RI3(I)+RI4(I)
0069             SUM1=(RI(1)+RI(2))*(X2(2)-X2(1))/4.
0070             SUM2=(RI(2)+RI(3))*(X2(3)-X2(2))/4.
0071             SUM3=(RI(3)+RI(4))*(X2(4)-X2(3))/4.
0072             SUM4=(RI(4)+RI(5))*(X2(5)-X2(4))/4.
0073             EN1=-(SUM2+SUM1)
0074             EN2=-SUM2
0075             EN4=SUM3
0076             EN5=SUM3+SUM4
0077             DD 50 I=1,5
0078          50 YOLD(I)=YR(I)
0079             YR(1)= EXP(EN1)
0080             YR(2)= EXP(EN2)
0081             YR(3)=1.0
0082             YR(4)= EXP(EN4)
0083             YR(5)= EXP(EN5)
0084             NCDUNT=0
0085             DD 1001 I=1,5
0086             IF( YR(I).GT. 2.0) YR(I)= 2.0
0087             IF( YR(I).LT. 0.2) YR(I)= 0.2
0088        1001   CONTINUE
0089             DD 110 I=1,5
0090             TEST=ABS(YDLO(I)-YR(I))
0091             IF(TEST-TOL4)110,110,119
0092         110 NCOUNT=NCOUNT+1
0093             IF(NCDUNT-5)119,140,119
0094         119 IF(INO-1)20,120,120
0095         120 IF (J-3) 80,10C,80
0096          80 IF (J-6) 90,100,90
0097          90 IF (J-9) 160,10C,160
0098         160 IF (J-12) 20,10C,20
0099         100 OD 60 I=1,5
0100         123 FORMAT (I4,I7,F10.5,5F8.4)
0101          60 WRITE (6,123) I,INOS1,DSDX2(I),RI2(I),RI3(I),RI4(I),RI(I),YR(I)
0102          20 CONTINUE
0103         140 DD 70 I=1,5
0104             VA2(I)=YR(I)*VA2(3)
0105             W2(I)=VA2(I)/CDS(BETA2(I))
0106             WR2(I)=-VA2(I)*DR(I)/2./CL
0107             W2(I) =SQRT(W2(I)*W2(I)+WR2(I)*WR2(I))
0108          70 T2(I)=TTE(I)-W2(I)**2/(0.24*C)
0109             IF(INDS1-1)251,149,149
0110         251 INOS1=INDS1+1
0111             DD 250 I=1,5
0112             AMR(I)=W2(I)/SQRT(GAM*ERRE*G*T2(I))
0113             IF(AMR(I)-.75)1,4,5
0114           1 IF(AMR(I)-.5)2,2,3
0115           2 BETA(3)=BETAM(1)
0116             GO TD 6
0117           3 BETA(3)=AB1+BB1*AMR(I)+CB1*AMR(I)**2
0118             GD TD 6
0119           4 BETA(3)=BETAM(3)
0120             GO TO 6
0121           5 BETA(3)=AB2+BB2*AMR(I)+CB2*AMR(I)**2
0122           6 IF (R(I)-RR3)221,222,223
0123         221 BETA2(I)=BETA(3)+(R(I)-RR3)/(RR1-RR3)*OBET(1)
0124             GO TO 250
0125         222 BETA2(I)=BETA(3)
0126             GD TO 250
0127         223 BETA2(I)=BETA(3)+(R(I)-RR3)/(RR5-RR3)*DBET(5)
0128         250 CDNTINUE
0129             OBETOX(1)=(BETA2(2)-BETA2(1))/(X2(2)-X2(1))
0130             OBETOX(5)=(BETA2(5)-BETA2(4))/(X2(5)-X2(4))
0131             DD 224 I=2,4
0132             M=I-1
```

```
      N=I+1
  224 DBETDX(I)=.5*((BETA2(N)-BETA2(I))/(X2(N)-X2(I))+(BETA2(I)-BETA2
     1(M))/(X2(I)-X2(M)))
      DC 225 I=1,5
      TAN1=-2.*TAN(BETA2(I))
      PROD=TAN1*DBETDX(I)
      SIN1=-2.*SIN(BETA2(I))**2/X2(I)
      RI1(I)=PROD+SIN1+DSDX1(I)
      SR1(I)=-4.*U(3)*COS(BETA2(I))*SIN(BETA2(I))/(VA2(3)*YR(I))
      SR2(I)=2.*U(3)*U(I)*COS(BETA2(I))**2/(VA2(3)**2*YR(I)**2)
      YOLD(I)=YR(I)
      AA(I)=(VA2(3)*YR(I)/COS(BETA2(I)))**2/(C*HE(I))
      RI3(I)=C*COS(BETA2(I))**2/(VA2(3)*YR(I))**2*DHEDX(I)
  225 CONTINUE
      GO TO 281
  149 DO 190 I=1,5
      WU2(I)=VA2(I)*TAN(BETA2(I))
      VU2(I)=WU2(I)+U(I)
      T2S(I)=TTE(I)-(TTE(I)-T2(I))/(1.-ZETAR(I))
      P2(I)=PTE(I)*(T2S(I)/TTE(I))**(GAM/(GAM-1.))
  190 PRAT2(I)=P2(I)/PTE(I)
  150 RETURN
      END
```

```
0001              SUBROUTINE FLOWR(PRAT,ZETAP,X,WI,PTE,PTO,TTE,TTO,AS,ZS,RS,AR,ZR,
                 1RR,M,WCHAN,VA,WPER,CODE,WLBM,B,R,TIPC,A)
0002              DIMENSION PRAT(10),ZETAP(10),X(10),WI(10),PTE(10),TTE(10),
                 1VA(10),WPER(10),B(20),A(10),R(10)
0003              COMMON /CUR/ COSL(10)
0004              COMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0005               COMMON /MAC/ IN
0006              COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0007              COMMON /CSS/ CJ,G,C1
0008              COMMON /ABA/ BA17,BLEX
0009              COMMON /IWI/ IND,INZ,IWR
0010               IN= 20
0011              C=BLEX
0012              A(3)=B(1)+B(2)*R(3)+B(3)*R(3)**2+B(4)*R(3)**3+B(5)*R(3)**4
0013              F1=1./(C+1.)
0014              F2=1./(3.*C+1.)
0015              F3=1./(5.*C+1.)
0016              F4=1./(7.*C+1.)
0017              F5=1./(9.*C+1.)
0018              F6=1./(11.*C+1.)
0019              PRATCR=(2./(GAM+1.))**(GAM/(GAM-1.))
0020              PHICR=(2./(GAM+1.))**(1./(GAM-1.))*SQRT(2.*GAM/(GAM+1.))
0021              DO 420 I=1,5
0022              IF (PRATCR-PRAT(I))400,402,402
0023          400 XE=1.-PRAT(I)**((GAM-1.)/GAM)
0024              GO TO 404
0025          402 XE=1.-PRATCR**((GAM-1.)/GAM)
0026          404 XE2=XE**2
0027              XE3=XE**3
0028              XE4=XE**4
0029              XEINV=1./(XE-1.)
0030              HNUM=XEINV+F2+XE*F3+XE2*F4+XE3*F5+XE4*F6
0031              HDEN=XEINV+F1+XE*F2+XE2*F3+XE3*F4+XE4*F5
0032              HSTAR=HNUM/HDEN
0033              XI=(HSTAR-1.)/(HSTAR-1.+ZETAP(I))
0034              IF (PRATCR-PRAT(I))406,408,408
0035          406 PHI=SQRT(2.*GAM/(GAM-1.)*(PRAT(I)**(2./GAM)-PRAT(I)**
                 1 ((GAM+1.)/GAM)))
0036              GO TO 410
0037          408 PHI=PHICR
0038          410 A(I)=B(1)+B(2)*R(I)+B(3)*R(I)**2+B(4)*R(I)**3+B(5)*R(I)**4
0039              ARAT=A(I)/A(3)
0040              IF(M-2)415,412,415
0041          412 IF(I-5)415,414,414
0042          414 ARAT=ARAT+2.*3.1416*R(5)*TIPC/(ZR*AR*RR*(X(5)-X(4)))
0043          415 IF(IND-1)420,416,416
0044          416 WRITE (6,418) XI,PHI,ARAT
0045          418 FORMAT (/5H  XI=, F6.4, 6H  PHI=, F7.5, 7H  ARAT=,F6.4)
0046          420 WI(I)=(PTE(I)/PTO)/SQRT(TTE(I)/TTO)*ARAT*XI*PHI*COSL(I)
0047              SUM1=(WI(1)+WI(2))*(X(2)-X(1))/2.
0048              SUM2=(WI(2)+WI(3))*(X(3)-X(2))/2.
0049              SUM3=(WI(3)+WI(4))*(X(4)-X(3))/2.
0050              SUM4=(WI(4)+WI(5))*(X(5)-X(4))/2.
0051              WSUM=SUM1+SUM2+SUM3+SUM4
0052              IF (M-1)428,426,428
0053          426 WREQ=WCHAN/(AS*ZS*RS)
0054              DIFF=ABS(WREQ-WSUM)
0055              GO TO 430
0056          428 WREQ=WCHAN/(AR*ZR*RR)
0057              DIFF=ABS(WREQ-WSUM)
0058         430  TAL= TOL1*WREQ
0059              IF (DIFF-TAL   )432,432,434
0060          432 VA(3)=VA(3)
0061              CODE=20.
0062              GO TO 442
0063          434 IF(WSUM-WREQ)436,432,438
0064          436  CONTINUE
0065              IF( PRAT(1).LT.PRATCR. AND. PRAT(5) .LT. PRATCR   ) GOTO 470
0066              VA(3)=VA(3)*(1.00+ DIFF/WREQ*1.01)
0067              GO TO 442
0068          438 VA(3)=VA(3)*(1.00- DIFF/WREQ*1.01)
0069          442 WPER(1)=0.
0070              WPER(2)=SUM1/WSUM
```

```
      WPER(3)=(SUM1+SUM2)/WSUM
      WPER(4)=(SUM1+SUM2+SUM3)/WSUM
      WPER(5)=1.
      IF(IND-1)450,423,423
  423 WRITE (6,422) (WI(I),I=1,5)
  422 FORMAT (/20H  FLOW INTEGRAND 1-5, 5F10.5)
      WRITE (6,424) SUM1,SUM2,SUM3,SUM4,WSUM
  424 FORMAT (/15H SUMS 1-4, WSUM, 5F10.5)
      WRITE (6,440) WSUM,WREQ,VA(3)
  440 FORMAT(35H REF FLOWS,COMPUTED-REQUIRED,AX VEL,2F10.4,F10.2)
      WRITE (6,444) WCHAN,WLBM
  444 FORMAT(/36H REF FLOW RATE CHANNEL-SQUARE INCHES,F8.5,18H FLOW RATE
     1-LBM/SEC,F8.5)
      WRITE (6,446) M
  446 FORMAT (/30H STREAMLINE FLOW FRACTIONS, M=,I2)
      WRITE (6,448) X(2),WPER(2),X(3),WPER(3),X(4),WPER(4)
  448 FORMAT(6F10.4)
       GOTO 450
  470   IN=1
  450 RETURN
      END
```

```
0001        OSUBROUTINE SLINE (RR,X,DWOX,WPER2,WPER1,HE,U,OHEDX,S,OSOX1,
            1ARF,RRF,FC1,FC2,COOE,M,8)
0002        ODIMENSION RR(10),X(10),DWDX(10),WI(10),WPER2(10),WPER1(10),HE(10),
            1OHEOX(10),S(10),DSDX1(10),U(10),B(20)
0003         COMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0004         CCMMON /IWI/ INC,INZ,IWR
0005         N7=0
0006         SAVE=RR(3)
0007         COOE=1.
0008         DO 700 I=1,4
0009         J=I+1
0010     700 DWOX(I)=(WPER2(J)-WPER2(I))/(X(J)-X(I))
0011         N=0
0012         OO 720 I=2,4
0013         K=I+1
0014         J=I-1
0015         IF (A8S(WPER2(I)-WPER1(I))-TOL2)716,716,702
0016     702 IF (WPER2(I)-WPER1(I))704,716,708
0017     704 XN=X(I)+(WPER1(I)-WPER2(I))/DWOX(J)
0018         IF(M-1)706,712,706
0019     706 SL=(HE(K)-HE(I))/(X(K)-X(I))
0020         OEL=2.*(SL-DHEOX(I))/(X(K)-X(I))
0021         OHEOX(I)=OHEOX(I)+OEL*(XN-X(I))
0022         HE(I)=HE(I)+DHECX(I)*(XN-X(I))
0023         SL=(S(K)-S(I))/(X(K)-X(I))
0024         DEL=2.*(SL-OSOX1(I))/(X(K)-X(I))
0025         OSOX1(I)=OSDX1(I)+OEL*(XN-X(I))
0026         S(I)=S(I)+OSOX1(I)*(XN-X(I))
0027         GO TO 712
0028     708 XN=X(I)-(WPER2(I)-WPER1(I))/DWDX(I)
0029         IF (M-1)710,712,710
0030     710 SL=(HE(I)-HE(J))/(X(I)-X(J))
0031         DEL=2.*(DHEDX(I)-SL)/(X(I)-X(J))
0032         DHEOX(I)=OHEDX(I)+OEL*(XN-X(I))
0033         HE(I)=HE(I)+DHEDX(I)*(XN-X(I))
0034         SL=(S(I)-S(J))/(X(I)-X(J))
0035         OEL=2.*(DSOX1(I)-SL)/(X(I)-X(J))
0036         CSOX1(I)=OSOX1(I)+OEL*(XN-X(I))
0037         S(I)=S(I)+OSOX1(I)*(XN-X(I))
0038     712 RR(I)=XN*SAVE
0039         GO TO 718
0040     716 N=N+1
0041         IF (N-3)720,730,720
0042     718 U(I)=U(I)*XN/X(I)
0043     720 CONTINUE
0044         OO 722 I=1,5
0045     722 X(I)=RR(I)/RR(3)
0046         FC1=RR(3)/SAVE
0047         FC2=FC1**2
0048         RRF=RR(3)
0049         ARF=B(1)+B(2)*RRF+B(3)*RRF**2+B(4)*RRF**3+8(5)*RRF**4
0050         IF(IND-1)732,721,721
0051     721 IF (M-1)729,732,729
0052     729 WRITE (6,724)
0053     724 FORMAT (/47H SLINE  XNEW   HENEW    DHEOX     S-NEW   DSOX1)
0054         OO 728 I=1,5
0055     726 FORMAT (I4,F9.4,F9.2,F9.4,F9.6,F9.5)
0056     728 WRITE (6,726) I,X(I),HE(I),OHEDX(I),S(I),DSOX1(I)
0057         GO TO 732
0058     730 CODE=40.
0059     732 RETURN
0060         END
```

```
0001            SUBROUTINE ALOS1(ZETAS,ZETAPS)
0002            OIMENSION  ALFA1(10),V1(10),RS(10),P1(10),T1(10),U (10),AMS1(10),
               1ZETAS(10),ZETAPS(10)
0003            COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0004            COMMON /CSS/ CJ,G,CI
0005            COMMON /AL1/  ALFA1,V1,TTO,RPM,RS,SI,TNI,H,O,CI,T1,P1,TO,TEI,ALI,
               18ESP,XX,ANG2O,AMS1,S,TN,C,TE,AL,SO,TNO,CO,TEO,U ,O1I,D1O,O2I,O2O,
               2ANG2I,ALFAX,TI,T,PTO,ALO,AMC
0006            COMMON /IWI/ INO,INZ,IWR
0007            CCMMON /AUS/ XCL
0008            CCMMON /ARE/ REE
0009            CCMMON /COZ/ ICOR,ICOZ,IINC,IAI,ICL,IAN,ICON
0010            COMMON /ABA/ BA17,8LEX
0011            COMMON /TR5/ TRA5
0012            IF(ICOR.NE.1)GOTO 5999
0013            RO=P1(3)/T1(3)*144./ERRE
0014            REE=RO*V1(3)*C/12./VIS2
0015            IF(ICL.EQ.0.ANO.IAI.EQ.0)8=.5
0016            IF(ICL.EQ.1.ANO.IAI.EQ.0)8=.25
0017            IF(ICL.EQ.0.ANO.IAI.EQ.1)B=.47
0018            IF(ICL.EQ.1.ANO.IAI.EQ.1)B=.37
0019            CALL AINLOS(0.,ANG2I,SI,CI,TI,O1I,O1O,O2I,O2O,0.,H,IWR,ZI1,ZI2,ZI3
               1,0.,100.,B,TNI)
0020            CALL AINLOS(0.,ALFAX,S ,C ,T ,O1I,O1O,O2I,O2O,0.,H,IWR,Z1 ,Z2 ,Z3
               1,0.,100.,B,TN )
0021            CALL AINLOS(0.,ANG2O,SO,CO,TO,O1I,O1O,O2I,O2O,0.,H,IWR,ZO1,ZO2,ZO3
               1,0.,100.,8,TNO)
0022            ZETAS(1)=ZI3/(1.+ZI3)
0023            ZETAS(3)=Z3 /(1.+Z3 )
0024            ZETAS(5)=ZO3/(1.+ZO3)
0025            GOTO 2020
0026       5999 CONTINUE
0027            IF(ICOR.NE.4)GOTO 6000
0028            OO 6001 MACC=1,5,2
0029            TRA1=90.-ALFA1(MACC)*57.29578
0030            TRA2=V1(MACC)*.3048
0031            TRA3=TTO/1.8
0032            TRA4=RPM*3.14159/30.*RS(MACC)/12.*.3048
0033            IF(MACC-3) 6002,6003,6004
0034       6002 CALL TRAUP2(TRA1,90.,TRA2,TRA3,EMME,GAM,SI,TNI,H,O,TRA5,CI,TRA4,
               10.,TR16,TRA7,TRA8,TRA9,ZETAS(MACC))
0035            GOTO 6001
0036       6003 CALL TRAUP2(TRA1,90.,TRA2,TRA3,EMME,GAM,S,TN ,H,O,TRA5,C ,TRA4,
               10.,TR26,TRA7,TRA8,TRA9,ZETAS(MACC))
0037            GOTO 6001
0038       6004 CALL TRAUP2(TRA1,90.,TRA2,TRA3,EMME,GAM,SO,TNO,H,O,TRA5,CO,TRA4,
               10.,TR36,TRA7,TRA8,TRA9,ZETAS(MACC))
0039       6001 CCNTINUE
0040       6000 CONTINUE
0041            IF(ICOR.NE.3) GOTO 2001
0042            XXX2=AMC*SQRT(TTO)
0043            OO 2003 MACC=1,5
0044            XXX1=-ALFA1(MACC)
0045            XXX3=AMS1(MACC)*SQRT(T1(MACC))
0046       2003  ZETAS(MACC) = ZAILOS( 0.,XXX1,XXX2, XXX3)
0047       2001 CONTINUE
0048            IF(ICOR.NE.2) GOTO 2020
0049            8AL1=3.14159/2.
0050            BAL5=D+H
0051            F1=1.*BLEX+1.
0052            F2=3.*BLEX+1.
0053            F3=5.*BLEX+1.
0054            F4=7.*BLEX+1.
0055            F5=9.*BLEX+1.
0056            F6=11.*BLEX+1.
0057            G1=F1+BLEX
0058            G2=F2+BLEX
0059            G3=F3+BLEX
0060            G4=F4+BLEX
0061            G5=F5+BLEX
0062            G6=F6+BLEX
0063            OO 2021 MACC=1,5,2
0064            XE=1.-(P1(MACC)/PTO)**EXP2
```

```
0065           ANUM=1.-(1.-XE)*(1./F1+XE/F2+XE**2/F3+XE**3/F4+XE**4/F5+XE**5/F6)
0066           ADEN=1-ANUM-(1.-XE)*(1./G1+XE/G2+XE**2/G3+XE**3/G4+XE**4/G5+XE**5/
              1G6)
0067           XX=ANUM/ADEN
0068           BAL2=BAL1-ALFA1(MACC)
0069           BAL3=P1(MACC)/T1(MACC)/ERRE*12.
0070           BAL4=RPM*3.14159/30.*RS(MACC)/12.
0071           IF(MACC-3) 2022,2023,2024
0072      2022 CALL BALJE(BAL1,BAL2,ALI,CI,SI,TEI,BAL3,VIS2,BAL4,BAL5,XX,0.,IWR,0
              1,BA16,BAL7,BAL8,V1(MACC),H)
0073           BAL6=BA16
0074           GOTO 2025
0075      2023 CALL BALJE(BAL1,BAL2,AL ,C ,S ,TE ,BAL3,VIS2,BAL4,BAL5,XX,0.,IWR,0
              1,BA26,BAL7,BAL8,V1(MACC),H)
0076           BAL6=BA26
0077           BA17=BAL7
0078             GO TO 2025
0079      2024 CALL BALJE(BAL1,BAL2,ALO,CO,SO,TEO,BAL3,VIS2,BAL4,BAL5,XX,0.,IWR,0
              1,BA36,BAL7,BAL8,V1(MACC),H)
0080           BAL6=BA36
0081      2025  ZETAS(MACC) = BAL6 +BAL7+ BAL8
0082      2021    CONTINUE
0083      2020    CONTINUE
0084           IF(ICOZ.LT.5) GCTO 2026
0085           DO 2027 MACC=1,5,2
0086           XY=ZETAS(MACC)/(1.-ZETAS(MACC))
0087           ZETAS(MACC)=(((1.+XY)/(  1.+XY*P1(MACC)/PTO)) **EXP2-1.)/
              1((PTO/P1(MACC))**EXP2-1.)
0088           IF(ICOZ.EQ.8) ZETAS(MACC)=(((1.+XY)/(1.+XY*BESP))**EXP2-1.)/
              1(1./BESP**EXP2-1.)
0089      2027  CONTINUE
0090      2026 CONTINUE
0091           IF(ICON.NE.3) GOTO 31
0092        30 DO 32 I=1,5,2
0093        32 ZETAPS(I)=ZETAS(I)
0094        31 IF(ICON.NE.2)GOTO 33
0095           IF(ICOR.EQ.4)ZETAPS(1)=TR16
0096           IF(ICOR.EQ.4)ZETAPS(3)=TR26
0097           IF(ICOR.EQ.4)ZETAPS(5)=TR36
0098           IF(ICOR.EQ.2)ZETAPS(1)=BA16
0099           IF(ICOR.EQ.2)ZETAPS(3)=BA26
0100           IF(ICOR.EQ.2)ZETAPS(5)=BA36
0101           IF(ICOR.EQ.1)ZETAPS(1)=ZI1/(1.+ZI1)
0102           IF(ICOR.EQ.1)ZETAPS(3)=Z1 /(1.+Z1 )
0103           IF(ICOR.EQ.1)ZETAPS(5)=ZO1/(1.+ZO1)
0104        33 CONTINUE
0105           IF(ICON.NE.1)GOTO 34
0106           DO 35 I=1,5,2
0107        35 ZETAPS(I)=ZETAS(I)
0108        34 CONTINUE
0109           RETURN
0110           END
```

```
0001          SUBROUTINE ALOS2(ZETAR,ZETAPR)
0002          DIMENSION  ALFA1(10),V1(10),RS(10),P1(10),T1(10),U (10),AMS1(10),
             1ZETAS(10),ZETAPS(10)
0003          DIMENSION  BETA2(10),W2(10),RR(10),P2(10),T2(10),U2(10),AMR2(10),
             1BETAO(10),ZETAR(10),ZETAPR(10),STALI(10),PTE(10),BETA1(10),TTE(10)
             2,WU2(10),W1(10)
0004          COMMON /ABA/ BA17,BLEX
0005          COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0006          COMMON /CSS/ CJ,G,C1
0007          COMMON /AL1/  ALFA1,V1,TTO,RPM,RS,SI,TNI,H,D,CI,T1,P1,TO,TEI,ALI,
             1BESP,XX,ANG20,AMS1,S,TN,C,TE,AL,SO,TNO,CO,TEO,U ,O1I,D1O,O2I,D2O,
             2ANG2I,ALFAX,TI,T,PTO,ALO,AMC
0008          COMMON /IWI/ INO,INZ,IWR
0009          COMMON /AUS/ XCL
0010          COMMON /ARE/ REE
0011          COMMON /COZ/ ICOR,ICOZ,IINC,IAI,ICL,IAN,ICON
0012          COMMON /AL2/  BETA2,BETA1,BETAO,W2,TTE,U2,SIR,TNIR,HR,DZ,CIR,TIPC,
             1SZ,TNR,CR,SOR,TNOR,COR,ALIR,ALR,ALOR,P2,WU2,W1    ,TEIR,TER,TEOR,
             2O1IR,O1OR,BETAZ,BETAI,ANM,TIR,TR,TOR,STALI,PTE,RS1,RS3,RS5,T2
0013          COMMON /TR5/ TRA5
0014          IF(ICOR.NE.1)GOTO 5999
0015          BETAO1=BETAO(1)/57.3
0016          BETAO3=BETAO(3)/57.3
0017          BETAO5=BETAO(5)/57.3
0018          RO=P2(3)/T2(3)*144./ERRE
0019          REE=RO*W2(3)*CR/12./VIS3
0020          IF(ICL.EQ.0.AND.IAI.EQ.0)B=.5
0021          IF(ICL.EQ.1.AND.IAI.EQ.0)B=.25
0022          IF(ICL.EQ.0.AND.IAI.EQ.1)B=.47
0023          IF(ICL.EQ.1.AND.IAI.EQ.1)B=.37
0024          CALL AINLOS(BETA1(1),BETAI,SIR,CIR,TIR,O2I,D2O,D1IR,D1OR,TIPC,HR,I
             1WR,ZI1,YY1,ZETAR(1),BETAO1   ,STALI(1),B,TNIR)
0025          CALL AINLOS(BETA1(3),ANM   ,SZ, CR,TR ,D2I,O2O,D1IR,D1OR,TIPC,HR,I
             1WR,Z1  ,YY1,ZETAR(3),BETAO3   ,STALI(5),B,TNR )
0026          CALL AINLOS(BETA1(5),BETAZ,SOR,COR,TOR,O2I,D2O,O1IR,D1OR,TIPC,HR,I
             1WR,ZO1,YY1,ZETAR(5),BETAO5   ,STALI(10),B,TNOR)
0027          DO 10 I=1,5,2
0028       10 ZETAR(I)=ZETAR(I)/(1.+ZETAR(I))
0029          GOTO 2040
0030     5999 CONTINUE
0031          IF(ICOR.NE.4) GOTO 6010
0032          DO 6011 MACC=1,5,2
0033          TRA1=90.+BETA2(MACC)*57.29578
0034          TRAX=90.-BETA1(MACC)*57.29578
0035          GIUD= BETAO(MACC)-BETA1(MACC)*57.29578
0036          IF( IINC.EQ.1. AND. GIUD.GE.0. ) TRAX=90.-BETAO(MACC)
0037          TRA2=W2(MACC)*.3048
0038          TRA3=TTE(MACC)/1.8
0039          TRA4=U2(MACC)*.3048
0040          IF(MACC-3) 6012,6013,6014
0041     6012 CALL TRAUP2(TRA1,TRAX,TRA2,TRA3,EMME,GAM,SIR,TNIR,HR,DZ,TRA5,CIR,
             1TRA4,TIPC,TR16,TRA7,TRA8,TRA9,ZETAR(MACC))
0042          GOTO 6011
0043     6013 CALL TRAUP2(TRA1,TRAX,TRA2,TRA3,EMME,GAM,SZ  ,TNR  ,HR,DZ,TRA5,CR  ,
             1TRA4,TIPC,TR26,TRA7,TRA8,YCL  ,ZETAR(MACC))
0044          GOTO 6011
0045     6014 CALL TRAUP2(TRA1,TRAX,TRA2,TRA3,EMME,GAM,SOR,TNOR,HR,DZ,TRA5,COR,
             1TRA4,TIPC,TR36,TRA7,TRA8,TRA9,ZETAR(MACC))
0046     6011 CONTINUE
0047          OHI=CP*TTO*(1.-(P2(3)/PTO)**EXP2)
0048          PSI=1./(1.-YCL*OHI*G*CJ/U2(3)/WU2(3))
0049          ZEZE= ZETAR(3)
0050          DO 6015 MACC=1,5,2
0051          ZETAR(MACC)=ZETAR(MACC)+(1.-ZEZE)* (1.-PSI*PSI)
0052     6015 CONTINUE
0053     6010 CONTINUE
0054          IF(ICOR.NE.3) GOTO 2004
0055          DO 2005 MACC=1,5
0056          GIUD= BETAO(MACC)-BETA1(MACC)*57.29578
0057          ANGL= BETA1(MACC)
0058          IF( IINC.EQ.1. AND. GIUD.GE.0. ) ANGL=BETAO(MACC)/57.29578
0059     2005 ZETAR(MACC)=ZA1LOS(ANGL        ,BETA2(MACC),W1(MACC),W2(MACC))
0060     2004 CONTINUE
```

```
0061           IF( ICOR. NE. 2) GOTO 2040
0062             BAL5=OZ+HR
0063           F1=1.*BLEX+1.
0064           F2=3.*BLEX+1.
0065           F3=5.*BLEX+1.
0066           F4=7.*BLEX+1.
0067           F5=9.*BLEX+1.
0068           F6=11.*BLEX+1.
0069           G1=F1+BLEX
0070           G2=F2+BLEX
0071           G3=F3+BLEX
0072           G4=F4+BLEX
0073           G5=F5+BLEX
0074           G6=F6+BLEX
0075             OO 2041  MACC=1,5,2
0076           XE=1.-(P2(MACC)/PTE(MACC))**EXP2
0077           ANUM=1.-(1.-XE)*(1./F1+XE/F2+XE**2/F3+XE**3/F4+XE**4/F5+XE**5/F6)
0078           AOEN=1-ANUM-(1.-XE)*(1./G1+XE/G2+XE**2/G3+XE**3/G4+XE**4/G5+XE**5/
              1G6)
0079           XX=ANUM/AOEN
0080              BAL1= 3.14159/2.+ BETA1( MACC)
0081           GIUO= BETAO(MACC)-BETA1(MACC)*57.2957B
0082           IF(IINC.EQ.1.ANO.GIUO.GE.0.) BAL1=3.14159/2.+BETAO(MACC)/57.2957B
0083              BAL2= 3.14159/2.+ BETA2(MACC)
0084             BAL3= P2(MACC)/T2(MACC)/ ERRE *12.
0085              BAL4= U2( MACC)
0086           IF( MACC-3) 2042,2043,2044
0087      2042    CALL BALJE( BAL1,BAL2,ALIR, CIR, SIR,TEIR,BAL3,VIS3, BAL4,BAL5,
              1 XX, TIPC,IWR,1,BA16, BAL7, BALB, W2( MACC), HR)
0088           BAL6=BA16
0089            GOTO 2045
0090      2043  CALL BALJE( BAL1, BAL2, ALR, CR, SZ, TER, BAL3, VIS3, BAL4, BAL5,
              1 XX, TIPC,IWR,1,BA26, BAL7, BALB, W2( MACC), HR)
0091           BAL6=BA26
0092            GOTO 2045
0093      2044 CALL BALJE(BAL1,BAL2,ALCR,COR,SOR,TEOR,BAL3,VIS3,BAL4,BAL5,
              1 XX, TIPC,IWR,1,BA36, BAL7, BALB, W2( MACC), HR)
0094           BAL6=BA36
0095      2045    ZETAR( MACC)= BAL6+ BAL7 + BALB
0096      2041    CONTINUE
0097      2040      CONTINUE
0098           IF(ICOZ.LT.5) GCTO 2046
0099           OO 2047 MACC=1,5
0100           XY=ZETAR(MACC)/(1.-ZETAR(MACC))
0101           ZETAR(MACC)=(((1.+XY)/(   1.+XY*P2(MACC)/PTE(MACC))) ** EXP2-1.)/
              1((PTE(MACC)/P2(MACC))**EXP2-1.)
0102           IF(ICOZ.EQ.B) ZETAR(MACC)=(((1.+XY)/(1.+XY*BESP))**EXP2-1.)/
              1(1./BESP**EXP2-1.)
0103      2046 CONTINUE
0104      2047 CONTINUE
0105           IF(ICON.NE.3) GCTO 31
0106        30 OO 32 I=1,5,2
0107        32 ZETAPR(I)=ZETAR(I)
0108        31 IF(ICON.NE.2)GOTO 33
0109           IF(ICOR.EQ.4)ZETAPR(1)=TR16
0110           IF(ICOR.EQ.4)ZETAPR(3)=TR26
0111           IF(ICOR.EQ.4)ZETAPR(5)=TR36
0112           IF(ICOR.EQ.2)ZETAPR(1)=BA16
0113           IF(ICOR.EQ.2)ZETAPR(3)=BA26
0114           IF(ICOR.EQ.2)ZETAPR(5)=BA36
0115           IF(ICOR.EQ.1)ZETAPR(1)=ZI1/(1.+ZI1)
0116           IF(ICOR.EQ.1)ZETAPR(3)=Z1 /(1.+Z1 )
0117           IF(ICOR.EQ.1)ZETAPR(5)=ZO1/(1.+ZO1)
0118        33 CONTINUE
0119           IF(ICON.NE.1)GOTO 34
0120           OO 35 I=1,5,2
0121        35 ZETAPR(I)=ZETAR(I)
0122        34 CONTINUE
0123           ZETAR (2)=ZETAR (1)+(RS(2)-RS1)/(RS3-RS1)*(ZETAR (3)-ZETAR (1))
0124           ZETAR (4)=ZETAR (3)+(RS(4)-RS3)/(RS5-RS3)*(ZETAR (5)-ZETAR (3))
0125           ZETAPR(2)=ZETAPR(1)+(RS(2)-RS1)/(RS3-RS1)*(ZETAPR(3)-ZETAPR(1))
0126           ZETAPR(4)=ZETAPR(3)+(RS(4)-RS3)/(RS5-RS3)*(ZETAPR(5)-ZETAPR(3))
0127           RETURN
```

```
 0128              END
```

```
0001          SUBROUTINE ANGAIN(ANG1,ANG2,S,C,O,E,TE,AM,CL,H,D,IWR,ANG21)
0002          COMMON /AUS/ XCL
0003          ANGOL=3.1415/18C.
0004           AO= ARCCOS( O/S)
0005           A1= -AO
0006          AO=+11.*ANGOL-1.146*AO
0007          AO=AO-4.*(S/E)*ANGOL
0008          ANG2=-(-AO+(-A1+AO)/2.*(1.+SIN(2.*3.1415*(AM-0.75))))
0009          IF(AM.LT.0.5)ANG2=AO
0010          IF(IWR.EQ.1)WRITE(6,1)        ANG2,AO,ANG1
0011        1 FORMAT(//5X, 7H ALFA1=,3E15.4)
0012          ANG21=ANG2
0013          IF(CL.LE.0.) GO TO 11
0014          AO =ATAN(   (1.-X*CL/H*COS(ANG1)/COS(ANG2)) *TAN(ANG2)+X*CL/H*
             1COS(ANG1)/COS(ANG2)* TAN(ANG1))
0015          A1= -ARCOS(O/S*(1.-CL/H)+ CL/H + CL/D)
0016          ANG2=-(-AO+(-A1+AO)/2.*(1.+SIN(2.*3.1415*(AM-0.75))))
0017          IF(AM.LT.0.5) ANG2=AO
0018          IF(IWR.EQ.1) WRITE(6,1) ANG2,AO,ANG1
0019     11        CONTINUE
0020          RETURN
0021          END
```

```
      FUNCTION ANGTRA(T,S,A)
      FK=SQRT(1.-T/S*(2.*A/S+T/S))
      ANGTRA=ARCOS(A/S/FK)
      RETURN
      END
```

```
      SUBROUTINE COEFFI
      DIMENSION Z(9,7),ORDIN(9),RX(9),RH(9),IR(9)
      COMMON /COE/ COEF(8,7),ASCIS(9),C(9),ALFA(7)
      NP=9
      READ(5,61) Z
   61 FORMAT(9F7.3)
      READ(5,62) (ASCIS(K),K=1,NP)
   62 FORMAT(9F5.2)
      DO 1 I=1,7
      DO 2 K=1,NP
    2 ORDIN(K)=Z(K,I)
       IF(I.EQ.5) M=7
       IF(I.NE.5) M=3
       IF(I.EQ.3) M=2
      CALL CHBFT(ASCIS,ORDIN,NP,C,M,RX,RH,IR)
        LM= M+1
        DO 5 L=1,LM
    5 COEF(L,I)=C(L)
    1 CONTINUE
      READ(5,65)ALFA
  65      FORMAT(7F5.C)
      RETURN
      END
```

```
      SUBROUTINE COEFF2
      DIMENSION Z(9,7),OROIN(9),RX(9),RH(9),IR(9)
      CCMMCN /CO2/ COEF(8,7),ASCIS(8),C(9),ALFA(6)
      NP=8
         DO 10 I=1,6
        READ(5,61) ( Z(K,I),K=1,NP)
10      CONTINUE
      REAO(5,62) (ASCIS(K),K=1,NP)
   61 FORMAT(9F7.3)
   62 FORMAT(9F5.2)
      OO 1 I=1,6
      DO 2 K=1,NP
    2 ORDIN(K)=Z(K,I)
          M=4
          IF( I.EQ.1) M=3
      CALL CHBFT(ASCIS,ORDIN,NP,C,M,RX,RH,IR)
        LM= M+1
        DO 5 L=1,LM
    5 COEF(L,I)=C(L)
    1 CCNTINUE
      REAO(5,65)ALFA
   65 FORMAT(7F5.0)
      RETURN
      END
```

```
      SUBROUTINE  CALYAO (SOLIO,ALFA1,RISUL)
C     USE CALYAO AFTER SUBROUTINE COEFFI
C
      COMMON/COE/COEF(8,7),ASCIS(9),C(9),ALFA(7)
      DIMENSION YNU(7),RX(6),RM(6),IR(6)
           DIMENSION YZ( 5) ,XZ(5)
      DO 1 I=1,7
        IF(I.EQ.5) M=7
        IF(I.NE.5) M=3
       IF(I.EQ.3) M=2
       M1= M+1
        DO 2 K=1,M1
    2 C(K)= COEF(K,I)
    1 YNU(I)=YC(SOLIO,C,M)
           IF( ALFA1.GT. ALFA(7)) GOTO 5
           IF( ALFA1.GT. ALFA(3)) GOTO 3
           IF( ALFA1.LT. ALFA(1)) GOTO 4
           IF( ALFA1.LT. ALFA(2)) GOTO 6
       RISUL= YNU(2)+ ( YNU(3)-YNU(2))/( ALFA(3)-ALFA(2))*( ALFA1-ALFA(2
     1))
         GOTO 1000
    5      RISUL= YNU(7)
      RETURN
    3  CONTINUE
          M=2
             MU=0
          DO 21 I=3,7
        MU= MU+1
        XZ(MU) = ALFA(I)
   21  YZ(MU)= YNU(I)
           CALL CHBFT(  XZ , YZ, MU, C,M,RX,RM,IR)
         RISUL= YC( ALFA1,C,M)
      RETURN
    4   RISUL= YNU(1)
      RETURN
    6    RISUL= YNU(1)+ ( YNU(2)-YNU(1))/( ALFA(2)-ALFA(1))* ( ALFA1- AL
     1FA(1))
 1000 RETURN
          END
```

```
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0001                 SUBROUTINE  CALYA2( SOLID,ALFA1,RISUL)
            C
            C             USE CALYA2 AFTER SUBROUTINE COEFF2
            C
0002                 COMMON /CO2/ COEF(8,7),ASCIS(8),C(9),ALFA(6)
0003                 DIMENSION YNU(7),RX(6),RM(6),IR(6)
0004                 DO 1 I=1,6
0005                     M=4
0006                     IF( I.EQ.1) M=3
0007                  M1= M+1
0008                   DO 2 K=1,M1
0009               2 C(K)= COEF(K,I)
0010               1 YNU(I)=YC(SOLID,C,M)
0011                     IF( ALFA1. LT. ALFA(1)) GOTO 16
0012                     IF( ALFA1. GE. ALFA(4))GOTO 10
0013                      M=2
0014                       CALL CH8FT( ALFA, YNU, 4,C,M, RX, RM, IR)
0015                       RISUL= YC( ALFA1,C,M)
0016                       GOTO 1000
0017             10     CONTINUE
0018                   IF( ALFA1.LE.ALFA(5)) RISUL= YNU(4)+(YNU(5)-YNU(4))/(ALFA(5)-
                  1    ALFA(4)) * ( ALFA1- ALFA(4))
0019                 IF( ALFA1.LE. ALFA(5)) GOTO 1000
0020                   IF( ALFA1.LE.ALFA(6)) RISUL= YNU(5)+(YNU(6)-YNU(5))/(ALFA(6)-
                  1    ALFA(5)) * ( ALFA1- ALFA(5))
0021                     IF( ALFA1.GT. ALFA(6)) GOTO 15
0022           1000 RETURN
0023             15  CONTINUE
0024                         RISUL= YNU(6)
0025                 RETURN
0026             16  CONTINUE
0027                       RISUL= YNU(1)
0028                 RETURN
0029                  END
```

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```
      FUNCTION FIG6(X)
      IF(X.LE.-3.2) FIG6=-1.6-1.92*X
      IF(X.GT.-3.2.AND.X.LE.-2.)FIG6=1.43*(-X)
      IF(X.GT.-2.  ANO.X.LE.1. )FIG6=0.45-1.21*X
      IF(X.GT.-1.  ANO.X.LE.-.14) FIG6=.95-0.71*X
      IF(X.GT.-0.14.ANO.X.LE.0.2) FIG6=1.
      IF(X.GT.0.2  .ANO.X.LE.0.6) FIG6=.86+0.70*X
      IF(X.GT.0.6  .AND.X.LE.1.0) FIG6=.2 +1.8 *X
      IF(X.GT.1.0  .ANO.X.LE.1.8) FIG6=-3.+5.   *X
      IF(X.GT.1.8) FIG6=-7.2+ 8.*X
      RETURN
      ENO
```

```
0001            SUBROUTINE AINLOS(ANG1,ANG2,S,C,T,O1I,O1O,O2I,O2O,CL,AH,IWR,YPO,
               1YSCL,YTOT,AING,ASTA,B,TN)
0002            CCMMON /COZ/ ICCR,ICOZ,IINC,IAI,ICL,IAN,ICON
0003            OIMENSION CFIG8(5)
0004            COMMON /ARE/ REE
0005            CFIG8(1)=0.5251E-01
0006            CFIG8(2)=0.10744E 00
0007            CFIG8(3)=-0.30647E 00
0008            CFIG8(4)=+0.363C1E 01
0009            CFIG8(5)=-0.32941E 01
0010            ANZZ= ANG1
          C
          C             LOSSES WITH AINLEY METHOO,AT ZERO INCIOENCE               O1O
          C                                                                       O2I
          C     ANG2 = WITHCUT CLEARANCE - RAOIANTS                               O2O
          C     ANG1,S,C,T  ARE GIVEN ACCORDING WITH AINLEY NOMENCLATURE          CL
          C                                                                       AH
          C     IN MAIN PROGRAM COEFFI,COEFF2 MUST BE CALLED BEFORE  AINLOS
          C
0011            OEG1=AING*180./3.1415
0012            OEG2=ANG2*180./3.1415
0013            SCL=S/C
0014            AN1=3.1415*(O1C*O1O-O1I*O1I)/4.*COS(AING)
0015            AN2=3.1415*(O2O*O2O-O2I*O2I)/4.*COS(ANG2)
0016             ASCIS= (AN2/AN1)**2/(1.+(O1I+O2I)/(O1O+O2O))
0017            Z=-OEG2
0018            CALL CALYAO(SOL,Z,YBO)
0019            CALL CALYA2(SOL,Z,Y81)
0020             TCC= T/C
0021            IF(TCC.GT. .25) TCC=.25
0022            IF(TCC.LT. 0.15)  TCC=0.15
0023            YPO=(  YBO+(DEG1/OEG2)*(OEG1/DEG2)*(Y81-Y80))*(5.*TCC)**(-AING/ANG
               12)
0024            IF(IWR.EQ.1)WRITE(6,1) Y80,Y81,YPO
0025            AINC=AING-ANG1
0026            AINC= -AINC
0027            ASC=AINC/ASTA *180./3.1415
0028            IF( ASC.GT.1.) ANG1= AING+ASTA*3.1415/180.
0029            IF( ASC.LT. -1.5) ANG1= AING-1.5*ASTA* 3.1415/180.
0030            IF( IWR.EQ.1.) WRITE(6,5) ASC, AING, ANG1
0031         5  FORMAT(/10X, 5HI/IS= ,F8.3,5HBETO=,F8.3,5HBET1=,F8.3//)
0032            ANGM=ATAN(0.5*(TAN(ANG1)+TAN(ANG2)))
0033            CLSC=2.*(TAN(ANG1)-TAN(ANG2))*COS(ANGM)
0034          1 FORMAT(/5X,12H Y IMPULSE =,E12.3,12H Y REACTION=,E12.3,10H Y ACTUA
               1L=,E12.3)
0035            IF(IWR.EQ.1) WRITE(6,2) ANGM,CLSC
0036          2 FORMAT(/5X,16H ANGM,CL/(S/C) =,2E15.5)
0037            YPO=YPO*FIG6(ASC)
0038            IF(IAI.EQ.1)GOTC 10
0039            ALAN=YC(ASCIS,CFIG8,4) /10.
0040            IF(IWR.EQ.1) WRITE(6,3) ASCIS,ALAN
0041          3 FORMAT(/5X,10H FIG.8, X=,E15.4, 3H Y=,E15.4)
0042            YSCL=(ALAN+B*CL/AH)* CLSC*CLSC*(COS(ANG2)/COS(ANGM))**2/COS(ANGM)
          C
0043            YTOT=YPO+YSCL
0044            IF(IWR.EQ.1) WRITE(6,4) YTOT,YSCL
          C     TRAILING EDGE THICKNESS EFFECT
          C
0045            ASC=TN/S
0046            IF(ASC.LE.0.04)YTOT=YTOT*(0.904+0.096/0.02*ASC)
0047            IF(ASC.LE.0.08.AND.ASC.GT.0.04)YTOT=YTOT*(1.096+.285/0.04*(ASC-.04
               1))
0048            IF(ASC.GT.0.08)YTOT=YTOT*(1.381+.31 /0.04*(ASC-0.8))
0049            IF(IWR.EQ.1) WRITE(6,4) YTOT
0050          4 FORMAT(/5X, 6H YTOT=,E15.5, 8H YS+YCL=,E15.5/)
0051            ANG1= ANZZ
0052            RETURN
0053       10   Z=CLSC*CLSC*COS(ANG2)*COS(ANG2)/ (COS(ANGM))**3
0054             IF( IAI.EQ.1) YSCL=0.334*C/AH*COS(ANG2)/COS(AING)*Z/10.
0055             IF( IAI.EQ.1) YTOT=( YPO+YSCL)*(REE   /200000.)**(-0.2)
0056               YTOT= YTOT+ 8*C/AH*(CL/C)**0.78*Z
0057             IF( IAI.EQ.1.AND.IWR.EQ.1) WRITE(6,8) YPO, YSCL, YTOT
0058        8   FORMAT(/1X, 8HY PROF.=,F10.5,8H Y SEC.=,F10.5, 8H Y TOT.=,F10.5)
```

```
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 0059              ANG1= ANZZ
 0060              RETURN
 0061              END
```

```
0001            SUBROUTINE TRAUP1
0002            CCMMON /TRA/ XPO1(5,8),XPO2(6,8),ALF1(8),ALFO1(5),ALFO2(6),
               1Y(10),Y1(10),C(6),RX(30),RY(30),IR(30),Z(6),C1(4,8),C2(4,8)
0003            DD 1 I=1,8
0004            READ(5,2)(XPO1(J,I),J=1,5)
0005            READ(5,3)(XPO2(J,I),J=1,6)
0006          2 FDRMAT(5F7.4)
0007          3 FDRMAT(6F7.4)
0008          1 CCNTINUE
0009            READ(5,33) (ALF1(I),I=1,8)
0010            READ(5,4)(ALFO1(I),I=1,5)
0011            READ(5,5)(ALFO2(I),I=1,6)
0012         33 FDRMAT(8F4.0)
0013          4 FORMAT(5F5.0)
0014          5 FORMAT(6F5.0)
0015            DO 6 I=1,8
0016            IF(I.LE.4) L=5
0017            IF(I.GE.5) L=4
0018            DO 7 J=1,5
0019          7 Y(J)=XPO1(J,I)
0020            DO 8 J=1,6
0021          8 Y1(J)=XPO2(J,I)
0022            CALL CHBFT(ALFO1,Y,5,C,3,RX,RH,IR)
0023            CALL CHBFT(ALFO2,Y1,L,Z,2,RX,RH,IR)
0024            DO 12 J=1,4
0025            C1(J,I)=C(J)
0026         12 C2(J,I)=Z(J)
0027          6 CONTINUE
0028            RETURN
0029            END
```

```
0001            FUNCTION XPO(ANG1,ANG2)
0002            COMMON /TRA/ XPO1(5,8),XPO2(6,8),ALF1(8),ALFO1(5),ALFO2(6),
               1Y(10),Y1(10),C(6),RX(30),RY(30),IR(30),Z(6),C1(4,8),C2(4,8)
0003            IF(ANG2-80.)1,2,3
0004          1 CONTINUE
0005            DO 4 I=1,8
0006            DO 5 J=1,4
0007          5 C(J)=C1(J,I)
0008          4 Y(I)=YC(ANG2,C,3)
0009            GO TO 10
0010          2 CONTINUE
0011            DO 6 I=1,8
0012          6 Y(I)=XPO1(5,I)
0013            GO TO 10
0014          3 CONTINUE
0015            DO 7 I=1,8
0016            DO 8 J=1,3
0017          8 C(J)=C2(J,I)
0018          7 Y(I)=YC(ANG2,C,2)
0019         10 CONTINUE
0020            DO 11 I=1,7
0021            IF(ANG1.GE.ALF1(I).AND.ANG1.LE.ALF1(I+1)) GO TO 100
0022            IF(ANG1.LT.ALF1(1)) GO TO 101
0023            IF(ANG1.GT.ALF1(8))GO TO 102
0024         11 CONTINUE
0025        100 CONTINUE
0026             XPO=Y(I)+(Y(I+1)-Y(I))/(ALF1(I+1)-ALF1(I))*(ANG1-ALF1(I))
0027            IF( ANG2. LT.40.) XPO=0.09-( 0.09-( XPO1(1,I)+ XPO1(1,I+1))/2.)*
               1(ANG2-20.)/20.
0028            RETURN
0029       101   XPO=Y(1)
0030            RETURN
0031       102  XPO=Y(8)
0032            RETURN
0033            END
```

```
      FUNCTION CSIM(V1,TO,EMME,GAM)
      ERRE= 848.*9.80665/EMME
      AST  =SQRT(2.*GAM/(GAM+1.)*ERRE*TO)
      AMACH=V1/AST
      IF(AMACH.LE.0.8)CSIM=1.
      IF(AMACH.LE.0.8)GOTO 1000
      IF(AMACH.LE.1.1)CSIM=1.-0.22/0.3 *(AMACH-0.8)
      IF(AMACH.LT.1.2.AND.AMACH.GT.1.1)CSIM=0.78+0.15/0.1*(AMACH-1.1)
      IF(AMACH.GT.1.2)CSIM=0.92+1.5/0.2*(AMACH-1.2)
 1000 RETURN
      END
```

```
0001            SUBROUTINE CID(ANG1,T,DEL,CSID,PSID,PSIF,HM,DM)
0002            OIMENSION  X(7),Y1(7),Y2(7)
0003            EF=1.-OEL/T/SIN(ANG1)
0004            OATA X/15.,20.,25.,30.,45.,60.,90./
0005            CATA Y1/ 1.06,1.1,1.17,1.225,1.63,2.1,2.45/
0006            DATA Y2/0.016,0.0315,0.049,0.072,0.159,0.260,0.4 /
0007            A=ANG1*180./3.1415
0008            DO 1 I=1,6
0009            IF(A.LE.X(1)) Y=1.+0.06*A/15.
0010            IF(A.GE.X(I).AND.A.LE.X(I+1)) Y=  +(Y1(I+1)-Y1(I))/(X(I+1)-X(I))*
               1(A-X(I)) + Y1(I)
0011            IF(A.LE.X(1))Z=Y2(1)*A/X(1)
0012            IF(A.GE.X(I).AND.A.LE.X(I+1)) Z=   (Y2(I+1)-Y2(I))/(X(I+1)-X(I))*
               1(A-X(I)) +Y2(I)
0013          1 CONTINUE
0014            IF(A.GT.X(7)) Y=1.
0015            IF(A.GT.X(7))Z=1.
0016            CSID=1.+(Y-1.)*2.*(1.-EF)
0017            PSID=Z*4.*(1.-EF)*(1.-EF)
0018            PSIF=0.025/0.09* HM*HM/DM/DM
0019            RETURN
0020            END
```

```
      FUNCTION CSIW(XPO,CSIP,T,ANG1,AH)
      CSIW=XPO*CSIP*T*SIN(ANG1)/AH
      RETURN
      END
```

```
      FUNCTION CSIR( S,AH,V1,ANG1,UM,XP)
      SL=S/AH
      IF(SL.LE.0.4)XL=XP*0.65/.4*SL
      IF(SL.GT.0.4.AND.SL.LE.0.8)XL=XP*(0.65+0.45/0.4*(SL-0.4))
      IF(SL.GT.0.8.AND.SL.LE.1.5)XL=XP*(1.1 +0.40/0.7*(SL-0.8))
      IF(SL.GT.1.5)XL=XP*(1.5+0.6/1.7*(SL-1.5))
      ASC=V1*SIN(ANG1)/UM
      XRO=0.025+0.015/0.64*ASC*ASC
       IF( ASC.LT. .2) XRO=0.024
      IF(ASC. GT. .95) XRO=0.0475
      CSIR=XRO*XL
      RETURN
      END
```

```
FORTRAN IV G LEVEL  18                 ALEAK             DATE = 70236          18/50/51               PAGE 0001

                 FUNCTION ALEAK (DELBET,DM,AL,CLE,ALFA1)
                 C1= 0.82-0.075*CELBET
                 ALEAK=C1*         (DM+AL)*CLE/DM/AL/COS(ALFA1)
                 RETURN
                 END
```

```
0001            SUBROUTINE TRAUP2(ANG1,ANGO,V1,TO,EMME,GAM  ,T,DEZ,HM,DM,CSIP,S,UM
               1,CL ,RPRO,R2,R3,YCL,RTOT)
0002            CSIP=1.
0003            R=   XPO(ANG1,ANGO)
0004            R1=CSIM(V1,TO,EMME,GAM)
0005            ANGZ= ANG1 *3.1415/180.
0006            CALL CID(ANGZ,T,DEZ,CSID,PSID,PSIF,HM,DM)
0007            R2=CSIW(R,CSIP,T,ANGZ,HM)
0008            R3=CSIR(S,HM,V1,ANGZ,UM,CSIP)
0009            RPRO=R*CSIP*R1*CSID+ PSIF+PSID
0010            IF(CL.LE.0.) YCL=0.
0011            IF(CL.LE.0.) GOTO 1000
0012            DEL=3.1416-(ANGC+ANG1)*3.1416/180.
0013            ALF1=1.5708-ANGZ
0014            YCL=ALEAK(DEL,DM,HM,CL ,ALF1)
0015       1000 RTOT=RPRO+R2+R3
0016            RETURN
0017            END
```

```
FORTRAN IV G LEVEL  18                 ZA1LOS            DATE = 70236         18/50/51              PAGE 0001

 0001                 FUNCTION  ZA1LOS(BETIN,BETEX,VIN,VEX)
                C     BETIN,BETEX ANGLES WITH AXIAL DIRECTION ,LIKE IN AINLEY
 0002                 ZA1LOS=(TAN(BETIN)-TAN(BETEX))/(.6+.8*COS(BETEX) )
 0003                 IF((VIN/VEX).LE..6) ZA1LOS=ZA1LOS*(.03+.1573*(VIN/VEX)**3.6)
 0004                 IF((VIN/VEX).GT..6) ZA1LOS=ZA1LOS*(.055+.15 *(VIN/VEX-.6))
 0005                   ZA1LOS= ZA1LOS/ (1.+ ZA1LOS)
 0006                 RETURN
 0007                 END
```

```
0001               SUBROUTINE BALJE (ANG1,ANG2,AL,C,T,TE,GAM2,VIS2,U,D,H,S,IWR,IR ,
                  1CSIP,CSIE,CSICL, C2,AH)
0002               COMMON /ABA/ BA17,BLEX
             C     IF IR = 1 IS A ROTOR
0003               DEG1=ANG1*180./3.1415
0004               DEG2=ANG2*180./3.1415
             C
             C     BALJE' METHOD OF LOSSES EVALUATION
             C
             C     PROFILE LOSSES
             C
             C     AL= BLADE CAMBER LINE HEIGHT - FT
             C     C = BLADE CHORD                 -FT
             C     T  = BLADE SPACING(PITCH)       -FT
             C     TE = BLADE TRAILING EDGE THICKNESS PROJECTION ON WHEEL PLANE
             C     TB = BLADE TRAILING EDGE THICKNESS
             C     GAM2,3 IN,EX ROTOR, LB/CU FT
             C     VIS2,3 INLET-EX ROT VISCOSITY LB/FT-SEC
             C     U =AT ROTOR TIP-FPS
             C     D= AT ROTOR TIP-FT
             C     ANG1=ANGLE BETWEEN INLET VELOCITY AND U -RAD
             C     ANG2= ANGLE BETWEEN OUTLET VELOCITY AND U-RAD
             C     H = BOUNDARY LAYER FORM FACTOR
             C     AH = BLADE HEIGHT
             C     S = TIP CLEARANCE -FT
0005               RE2=C2*AL *GAM2/VIS2
0006               IF(IWR.EQ.1) WRITE(6,2) RE2
0007             2 FORMAT(/5X,4HRE2=,E15.5)
0008               ARE2=ALOG10(RE2)
0009               EFRE2=71.0/ARE2**2.58+1.-TANH (1.96508*ARE2-8.51713)
0010               IF(IWR.EQ.1) WRITE(6,3) EFRE2
0011             3 FORMAT(/5X, 6HEFR2=,E15.5)
0012               SIN1=SIN(ANG1)
0013               SIN2=SIN (ANG2)
0014               ZETAL=0.0021*(   (1.-(SIN2/SIN1)**4.5)/(1.-SIN2/SIN1))**0.8
0015               ZETALC=EFRE2*ZETAL
0016               IF(IWR.EQ.1)WRITE(6,4)ZETAL,ZETALC
0017             4 FORMAT(/5X,14H ZET/L,RE=REF=,E15.5,13H ZET/L RE=RE2,E15.5/)
0018               ZETAST=ZETALC*AL/T/SIN2
0019               DELAST=H*ZETAST
0020               ANUM=        COS(ANG2)*COS(ANG2)*(1.-DELAST-ZETAST-TE/T)**2/(1.-DEL
                  1AST-TE/T)**2+(SIN2*(1.-DELAST-TE/T))**2
0021               DEN=1.+2*SIN2*SIN2 * ((1.-DELAST- TE/T)**2-(1.-DELAST-ZETAST-TE/T)
                  1)
0022               CSIP=1.-ANUM/DEN
0023               IF(IWR.EQ.1)WRITE(6,5) CSIP,ANUM,DEN,H
0024             5 FORMAT(/5X,27H PROFILE LOSS COEFFICIENT =,E15.5,3E20.4)
0025               CSI=0.3* (   0.0388*(SIN2/SIN1+0.08)*(1.+(DEG1-DEG2)/100.) +
                  10.000337*(10.*(SIN2/SIN1+0.08))**(1.5+(DEG1-DEG2)/160.))
0026               IF(SIN2. GT. SIN1) CSI= CSI*SIN2*SIN2/SIN1/SIN1
0027               CSIE=CSI*C/AH
0028                IF( IR. EQ.1) CSIE= CSIE/0.3*( .3+TANH(2.857*H*BA17))
0029               IF(IWR.EQ.1) WRITE(6,6 ) CSIE,CSI
0030             6 FORMAT(/5X,28H ENDWALL  LOSS COEFFICIENT =,E15.5,E20.4)
0031               IF( IR.NE. 1) CSICL=0
0032               IF(IR.NE.1) GO TO 1000
0033               CSIS=0.0696*TANH (13.*S/C)
0034               DELU= COTAN(ANG2)-COTAN(ANG1)
0035               BETINF=ATAN(1./(COTAN(ANG1)+DELU/2.))
0036               CSIC=CSIS*C/AH*SIN(BETINF)*DELU
0037                  CSICL= CSIC
0038               IF(IWR.EQ.1) WRITE(6,7) CSICL,DELU,BETINF
0039             7 FORMAT(/5X,27HLEAKAGE LOSS  COEFFICIENT=,E15.5,2E20.5)
0040               IF(CSICL.LE.0.) CSICL=0.
0041          1000 RETURN
0042               END
```

```
0001            SUBROUTINE PARAB (V,I,J,K,A,B,C,VAR1,VAR2,VAR3)
0002            OIMENSION V(10)
0003            COMMON INO
0004            VAR12=VAR1**2
0005            VAR22=VAR2**2
0006            VAR32=VAR3**2
0007            D=VAR2*VAR32-VAR3*VAR22+VAR1*(VAR22-VAR32)+VAR12*(VAR3-VAR2)
0008           0DA=V(I)*(VAR2*VAR32-VAR3*VAR22)+VAR1*(VAR22*V(K)-VAR32*V(J))
               1 + VAR12*(V(J)*VAR3-V(K)*VAR2)
0009            DB=V(J)*VAR32-V(K)*VAR22+V(I)*(VAR22-VAR32)+VAR12*(V(K)-V(J))
0010            OC= VAR2*V(K)-VAR3*V(J)+VAR1*(V(J)-V(K))+V(I)*(VAR3-VAR2)
0011            A=0A/0
0012            B=0B/0
0013            C=0C/0
0014            RETURN
0015            ENO
```

```
C      SUBROUTINE CHBFT
C
C      PURPOSE:
C          SUBROUTINE CHBFT  EVALUATES THE COEFFICIENTS OF AN MTH ORDER
C          POLYNOMIAL P(X)=A(1)+A(2)*X+A(3)*X**2+...+A(M+1)X**M  SUCH
C          THAT THE MAXIMUM ERROR ABS(P(X(I))-Y(I)) IS A MINIMUM OVER
C          THE N (N.GT.M+1) SAMPLE POINTS X(I),Y(I), I=1,2,...,N.  THE
C          X(I) MUST FORM A STRICTLY MONOTONIC SEQUENCE; I.E.,
C          X(1).LT.X(2).LT.X(3).LT....X(N). THIS SUBROUTINE IS A
C          CONVERSION FROM ALGOL TO FORTRAN OF ALGORITHM 318, CHEBYSCHEV
C          CURVE-FIT FROM"COMMUNICATIONS OF THE ACM"VOL.10,NUMBER 12,
C          DECEMBER,1967. THE AUTHOR OF THE ALGOL VERSION WAS
C          J. BOOTHROYD FROM THE UNIVERSITY OF TASMANIA.
C
C      USAGE:
C          CALL CHBFT (X,Y,N,A,M,RX,RH,R)
C
C          DESCRIPTION OF PARAMETERS:
C          X     -ARRAY OF ABSCISSAE DIMENSIONED REAL*4 X(N)
C          Y     -ARRAY OF ORDINATES DIMENSIONED REAL*4 Y(N)
C          N     -NUMBER OF SAMPLE POINTS  (INTEGER)
C          A     -ARRAY OF THE OUTPUTTED POLYNOMIAL COEFFICIENTS
C                 DIMENSIONED AT LEAST A(M+2) (REAL*4)
C          M     -ORDER OF DESIRED APPROXIMATING POLYNOMIAL
C          RX    -WORK ARRAY DIMENSIONED AT LEAST REAL*4 RX(M+2)
C          RH    -WORK ARRAY DIMENSIONED AT LEAST REAL*4 RH(M+2)
C          R     -INTEGER WORK ARRAY DIMENSIONED AT LEAST R(M+2)
C
C      REMARKS:
C          THE POLYNOMIAL P(X) IS A BEST-FIT POLYNOMIAL IN THE CHEBYSCHEV
C          SENSE AS DESCRIBED BY STIEFEL(NUMERICAL METHODS OF
C          TCHEBYCHEFF APPROXIMATION), IN LANGER(ED.),"ON NUMERICAL
C          APPROXIMATION",U.OF WISCONSIN PRESS, 1959, PP. 217-232.
C          STIEFEL (P.221) SHOWS THAT THE PROCEDURE MUST TERMINATE AFTER
C          A FINITE NUMBER OF STEPS. AT EXIT THE ABSOLUTE VALUE OF
C          A(M+1) YIELDS THE FINAL REFERENCE DEVIATION. NEGATIVE A(M+1)
C          INDICATES THAT THE PROCEDURE HAS BEEN TERMINATED FOLLOWING
C          THE DETECTION OF CYCLING.
C
C      NOTE:  DIVIDED DIFFERENCES AND NEWTON'S INTERPOLATING FORMULA IS
C          USED FOR COMPUTING THE POLYNOMIAL COEFFICIENTS.
C
C
       SUBROUTINE CHBFT(X,Y,N,A,M,RX,RH,R)
       REAL*4 NEXTHI
       INTEGER RI,RJ,R(1)
       DIMENSION X(1),Y(1),A(1),RX(1),RH(1)
       MPLUS1=M+1
       MPLUS2=M+2
       PREVH=0.0
C      DETERMINE INDEX VECTOR FOR INITIAL REFERENCE SET
       R(1)=1
       R(MPLUS2)=N
       D=(N-1)/MPLUS1
       H=0
       DO 1 I=2,MPLUS1
       R(I)=H+1.0
     1 H=H+D
     2 H=-1.0
C      SELECT M+2 REFERENCE PAIRS AND SET ALTERNATIVE DEVIATION VECTOR
       DO 3 I=1,MPLUS2
       RI=R(I)
       RX(I)=X(RI)
       A(I)=Y(RI)
       H=-H
     3 RH(I)=H
C      COMPUTE M+1 LEADING DIVIDED DIFFERENCES
       DO 4 J=1,MPLUS1
       I1=MPLUS2
       AI1=A(I1)
       RHI1=RH(I1)
       I=MPLUS1
     5 DENOM=RX(I1)-RX(I-J+1)
```

```
0028          AI=A(I)
0029          RHI=RH(I)
0030          A(I1)=(AI1-AI)/DENOM
0031          RH(I1)=(RHI1-RHI)/DENOM
0032          I1=I
0033          AI1=AI
0034          RHI1=RHI
0035          I=I-1
0036          IF(I-J) 4,5,5
0037        4 CCNTINUE
      C       EQUATE (M+1) THE DIFFERENCE TO ZERO TO DETERMINE H
0038          H=-A(MPLUS2)/RH(MPLUS2)
      C       WITH H KNOWN, CCMBINE THE FUNCTION AND DEVIATION DIFFERENCES
0039          DO 6 I=1,MPLUS2
0040        6 A(I)=A(I)+RH(I)*H
      C       COMPUTE POLYNOMIAL COEFFICIENTS
0041          J=M
0042        7 XJ=RX(J)
0043          I=J
0044          AI=A(I)
0045          JPLUS1=J+1
0046          DO 8 I1=JPLUS1,MPLUS1
0047          AI1=A(I1)
0048          A(I)=AI-XJ*AI1
0049          AI=AI1
0050        8 I=I1
0051          J=J-1
0052          IF(J-1) 9,7,7
0053        9 CONTINUE
      C       IF THE REFERENCE DEVIATION IS NOT INCREASING MONOTONICALLY
      C       THEN EXIT
0054          HMAX=ABS(H)
0055          IF(HMAX.GT.PREVH) GO TO 29
0056          A(MPLUS2)=-HMAX
0057          RETURN
      C       FIND THE INDEX,IMAX,AND VALUE,HIMAX, OF THE LARGEST ABSOLUTE
      C       ERROR FOR ALL SAMPLE POINTS
0058       29 A(MPLUS2)=HMAX
0059          PREVH=HMAX
0060          IMAX=R(1)
0061          HIMAX=H
0062          J=1
0063          RJ=R(J)
0064          DO110 I=1,N
0065          IF(I.EQ.RJ) GO TO 11
0066          XI=X(I)
0067          HI=A(MPLUS1)
0068          K=M
0069       12 HI=HI*XI+A(K)
0070          K=K-1
0071          IF(K-1)112,12,12
0072      112 HI=Y(I)
0073          ABSHI=ABS(HI)
0074          IF(ABSHI.LE.HMAX) GO TO 11
0075          HMAX=ABSHI
0076          HIMAX=HI
0077          IMAX=I
0078          GO TO110
0079       11 IF(J.GE.MPLUS2) GO TO110
0080          J=J+1
0081          RJ=R(J)
0082      110 CONTINUE
      C       IF THE MAXIMUM ERROR OCCURS AT A NONREFERENCE POINT, EXCHANGE THIS
      C       POINT WITH THE NEAREST REFERENCE POINT HAVING AN ERROR  OF THE
      C       SAME SIGN AND REPEAT
0083          IF(IMAX.EQ.R(1)) RETURN
0084          DO 14 I=2,MPLUS2
0085          IF(IMAX.LT.R(I)) GO TO 15
0086       14 CONTINUE
0087          I=MPLUS2
0088       15 NEXTHI=H
0089          IF((I-I/2*2).NE.0) NEXTHI=-H
0090          IF(HIMAX*NEXTHI.GE.0) GO TO 115
```

```
      IF(IMAX.GE.R(1))      GO TO 116
      J1=MPLUS2
      J=M
  117 R(J1)=R(J)
      J1=J
      J=J-1
      IF(J-1)118,117,117
  118 R(1)=IMAX
      GO TO 2
  116 IF(IMAX.LE.R(MPLUS2)) GO TO 120
      J=1
      DO 121 J1=1,MPLUS2
      R(J)=R(J1)
  121 J=J1
      R(MPLUS2)=IMAX
      GO TO 2
  115 R(I)=IMAX
      GO TO 2
  120 R(I-1)=IMAX
      GO TO 2
      END
```

```
      FUNCTION YC(XBAR,C,M)
      DIMENSION C(1)
      YC=0
      IF(XBAR.EQ.0.) YC=C(1)
      IF(XBAR.EQ.0.) GOTO 10
      M1=M+1
      DO 1 I=1,M1
    1 YC=YC+C(I)*XBAR**(I-1)
   10 CONTINUE
 1000 RETURN
       END
```

BIBLIOGRAPHY

1. Vavra, M. H. "Aerothermodynamic and Flow in Turbomachines", Wiley and Sons, N. Y., 1960, pg. 439 - 470.
2. Eckert, H. E. "Performance Analysis and Initial Tests of a Transonic Turbine Test Rig," NPS Thesis, May 1966.
3. Harrison, R. G. "An Analysis of Single Stage Axial-Flow Turbine Performance Using Three-Dimensional Calculating Methods," NPS Thesis, September 1967.
4. Vavra, M. H. and Macchi, E. "Comparison of Performance Prediction Methods for Axial Turbine Stages," to be published.
5. Vavra, M. H., "Axial Flow Turbines," in Lecture Series 15, von Karman Institute for Fluid Dynamics, Brussels, April 1969.
6. Ainley, D. G. and Mathieson, G. C. R., "A Method of Performance Estimation for Axial-Flow Turbines," Aeronautical Research Council, R&M No. 2974, 1957.
7. Dunham, J. and Came, P. M., "Improvements to the Ainley-Mathieson Method of Turbine Performance Prediction," ASME paper 70-GT-2.
8. Balje', O. E. and Binsley, R. L.," "Axial Turbine Performance Evaluation, Part A - Loss Geometry Relationships," Journal of Engineering for Power, Trans. ASME, Oct. 1968.
9. Lonherr, F. K. and Carter, A. F., "Correlations of Turbine Blade Total Pressure Loss Coefficients Derived from Achievable Stage Efficiency Data," ASME paper 68-Fe-51, 1968.
10. Traupel, W., "Thermische Turbomaschinen,"Vol. 1, Springer Verlag, Berlin/Gottingen, Heidelberg, 1958, pg 269-298.

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13. ABSTRACT

The report presents a computer program for prediction of performance of single-stage axial turbines of given geometry. The three-dimensional method developed by Vavra is applied, taking account of streamline curvatures and slopes, as well as enthalpy and entropy gradients in the solutions of the equation of motion, and of boundary layer thicknesses in the continuity equation.

A choice among five different loss correlation methods and two flow angles correlations is offered. Loss coefficients and flow angles are automatically calculated from blading geometry and actual flow conditions for every streamline, according to the selected correlation method.

A fair agreement of predictions with several actual turbines experimental results was found in ref. [4], where also the applicability of different available correlations is discussed.

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